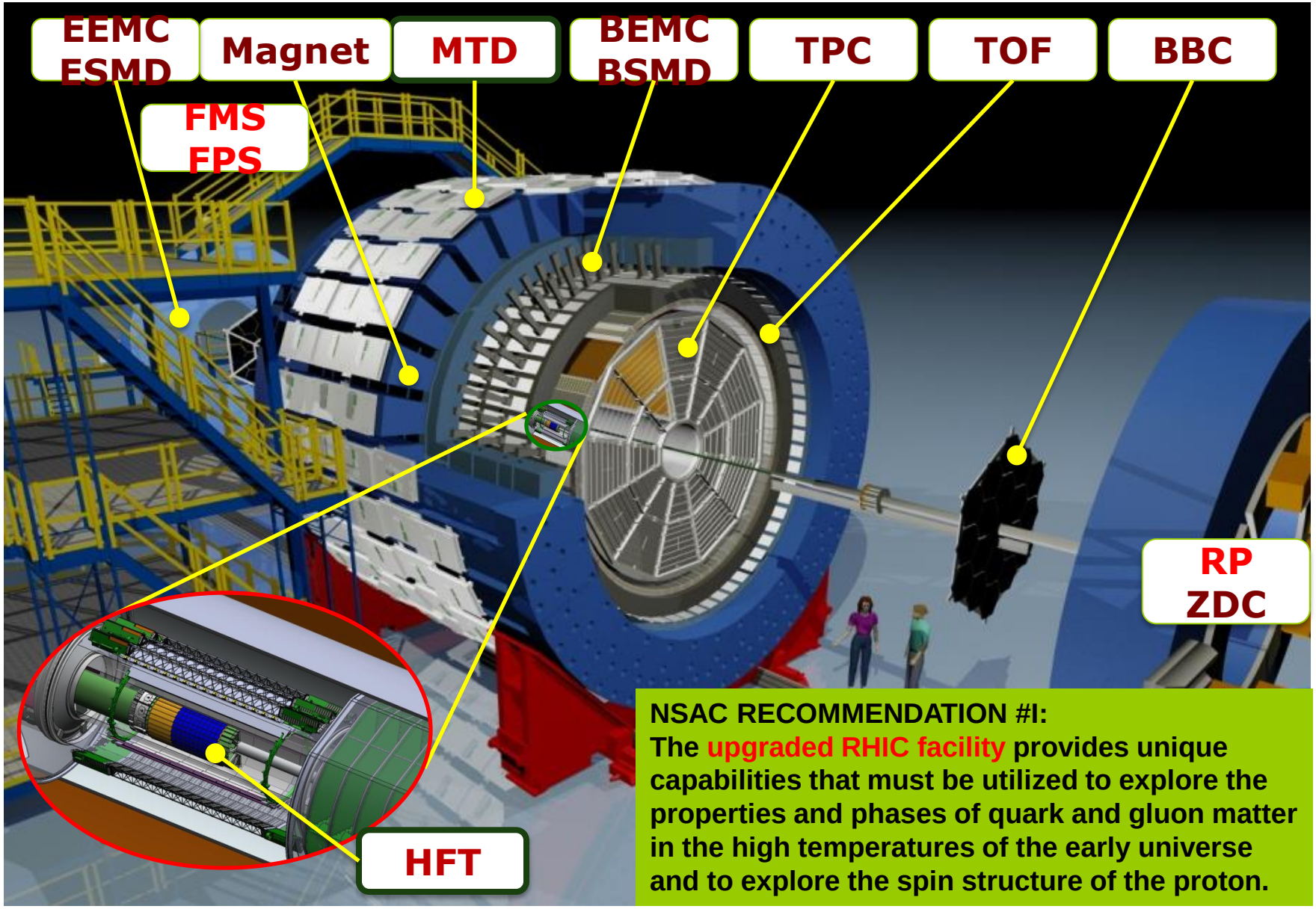
Zhangbu Xu
(Brookhaven National Lab)

1. Recent Highlights and Accomplishments
2. Performance with Run16 High-Statistics Dataset
3. Programs in next 2 years
4. BES II Program
5. Detector Upgrades
6. Longer Term and Summary

U.S. DEPARTMENT OF ENERGY | Office of Science

STAR Detector System

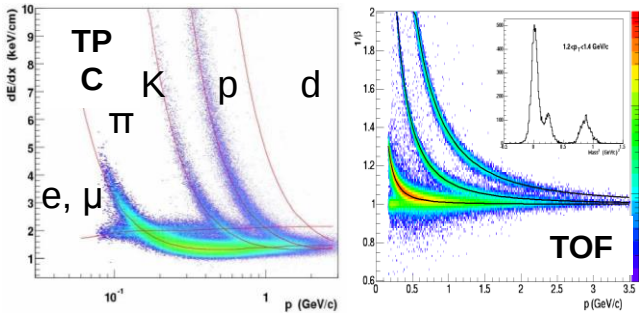
15 fully functioning detector systems



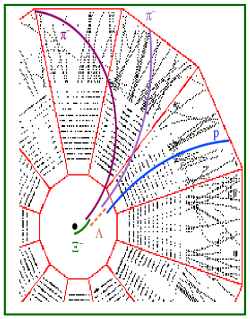
NSAC RECOMMENDATION #I:
The upgraded RHIC facility provides unique capabilities that must be utilized to explore the properties and phases of quark and gluon matter in the high temperatures of the early universe and to explore the spin structure of the proton.

X10^3 increases in DAQ rate since 2000, most precise Silicon Detector (HFT 2014-16)

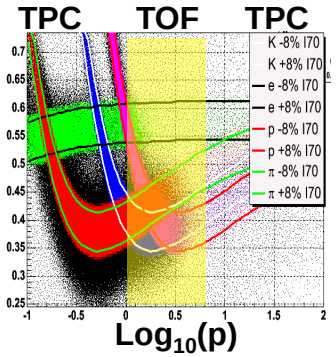
Particle Identification at STAR

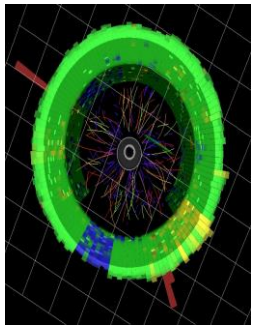


Charged hadrons

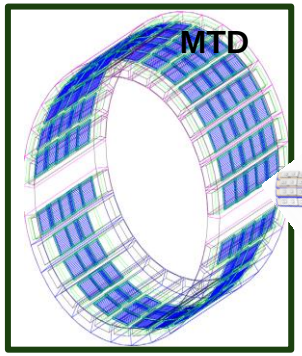


Hyperons & Hyper-nuclei



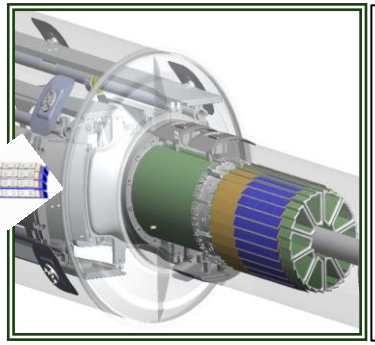


EM particles

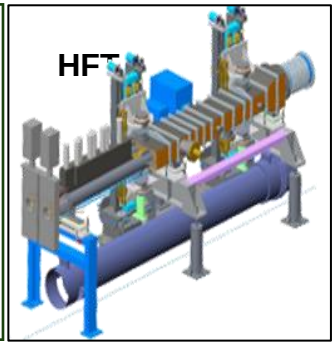


Jets & Correlations

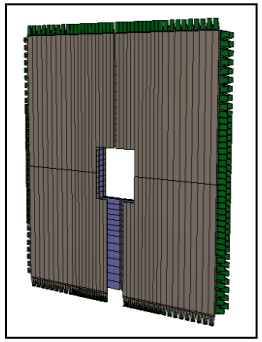
High p_T muons



Heavy-flavor hadrons



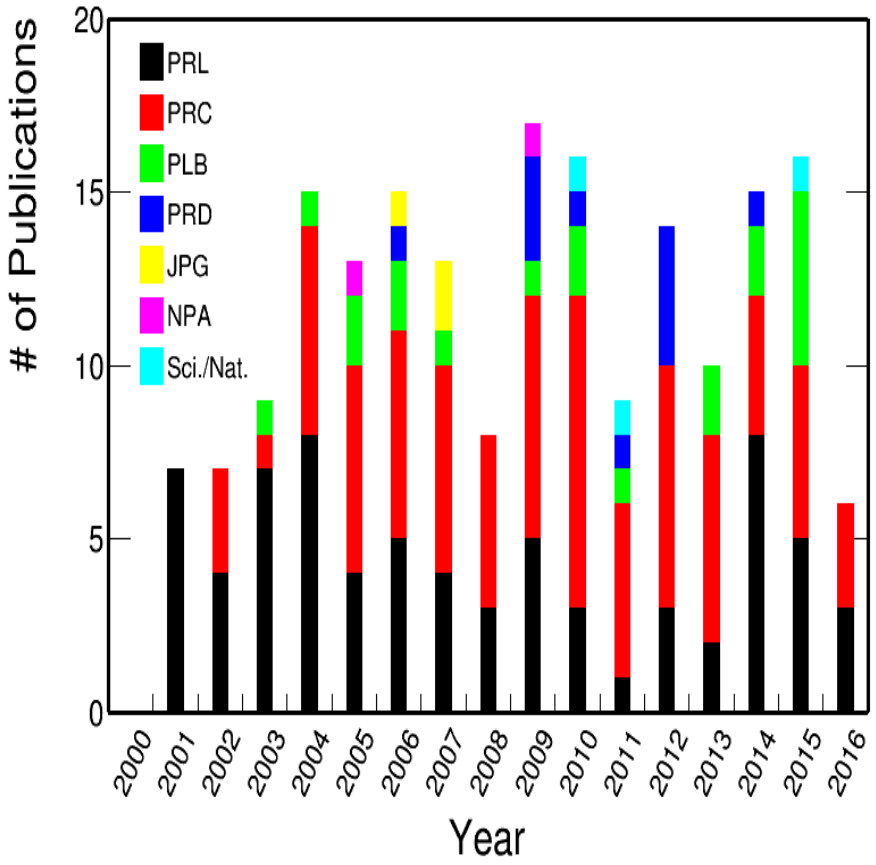
Forward protons



Forward photons

Multiple-fold correlations for identified particles!

STAR Publication History



June 2015 – 2016

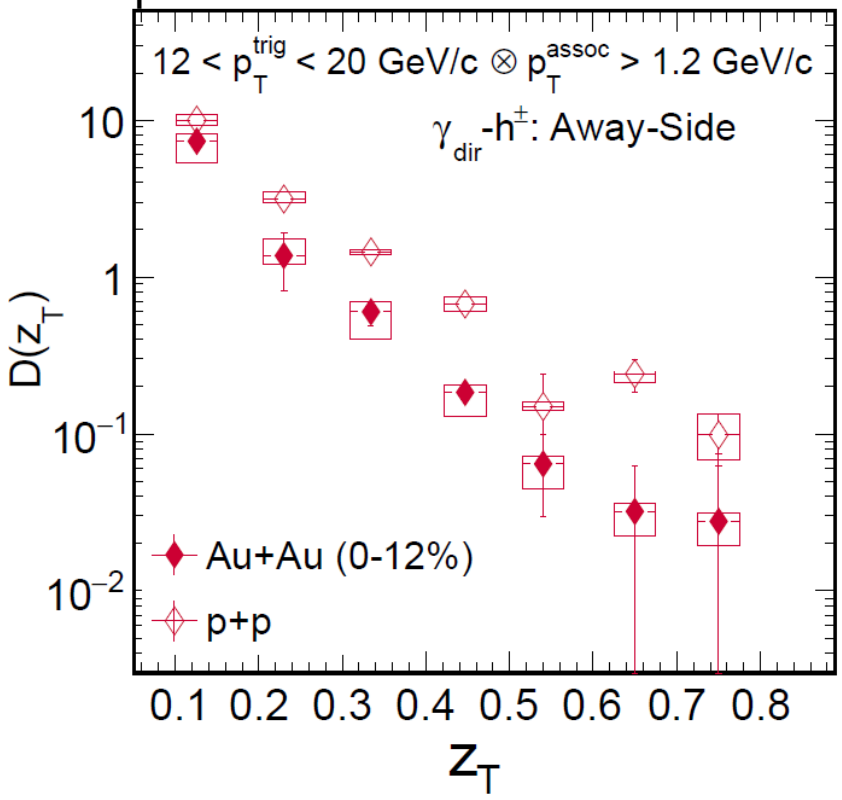
- 17 published papers (incl. 1 accepted)
  - 7 PRLs, 6 PRCs, 3 PLB, 1 Nature
    - 3 *PRL Editor's Suggestion*
- 5 in journal review
- 13 in collaboration (GPC) review process
- 9 paper proposals readied for GPC
- 14 PhD graduations

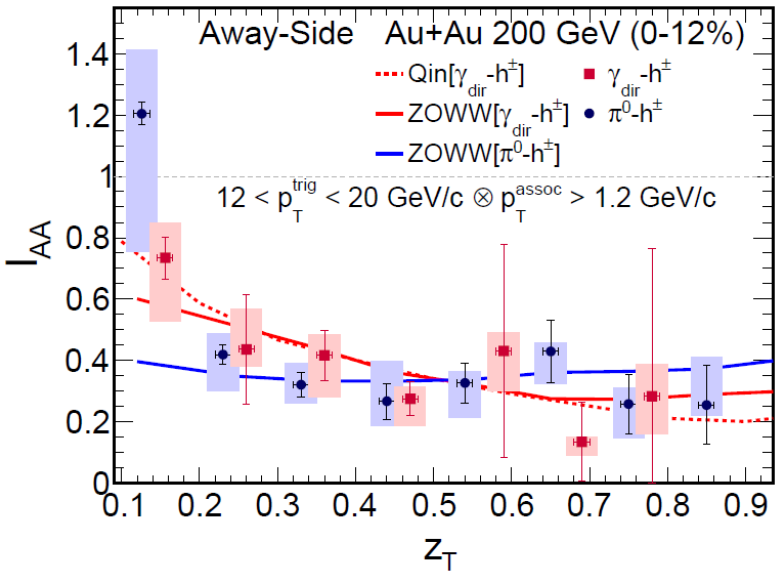
Highlights of Recent Results

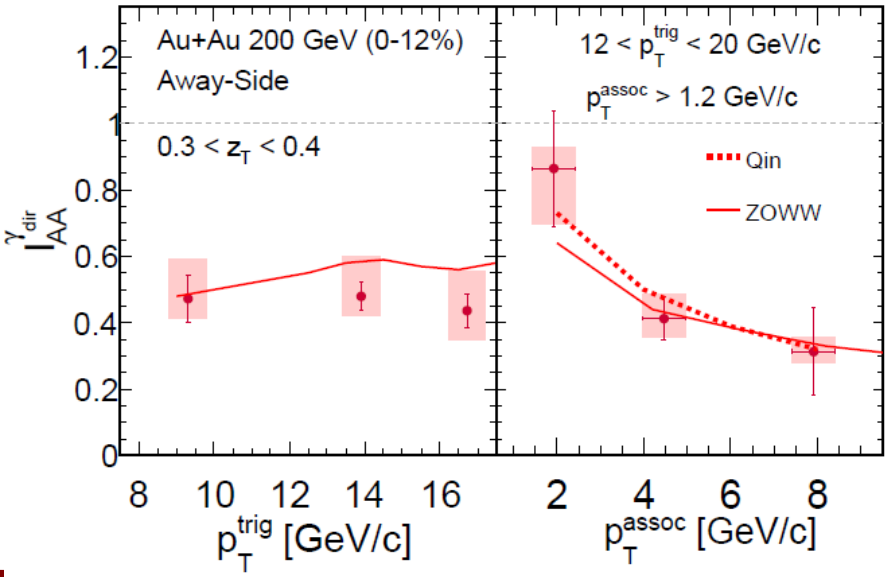
- Jets
- Heavy-Flavor
- Dileptons
- v_n
- Spin
- Chiral Magnetic Effect
- Global Polarization
- BES-I highlights

γ-jet correlation

Paper submitted: arXiv:1604.01117

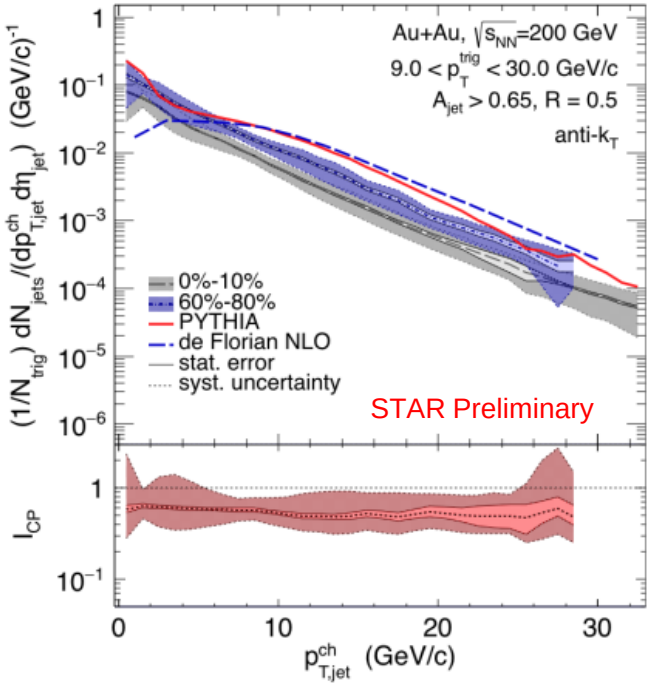


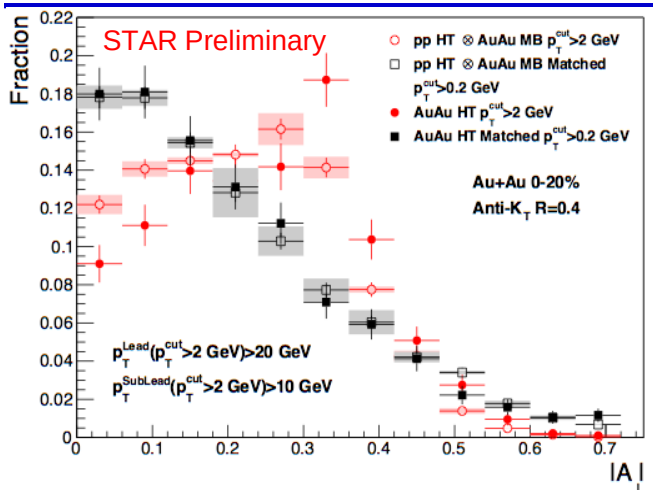


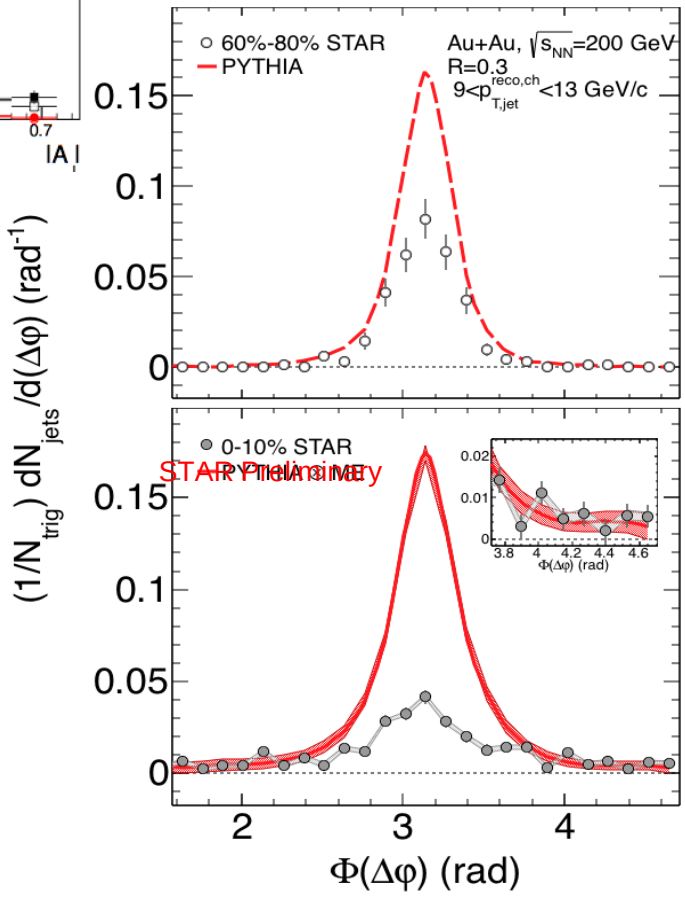


- Golden probe of Jet Energy Loss calibrated energy from γ for FF (Z_T)
- Cover large range of Z
- γ and π^0 triggered hadron I_{AA} similar
- Suppression independent of jet energy
- Lost energy reappear at low p_T

Semi-inclusive hadron jets

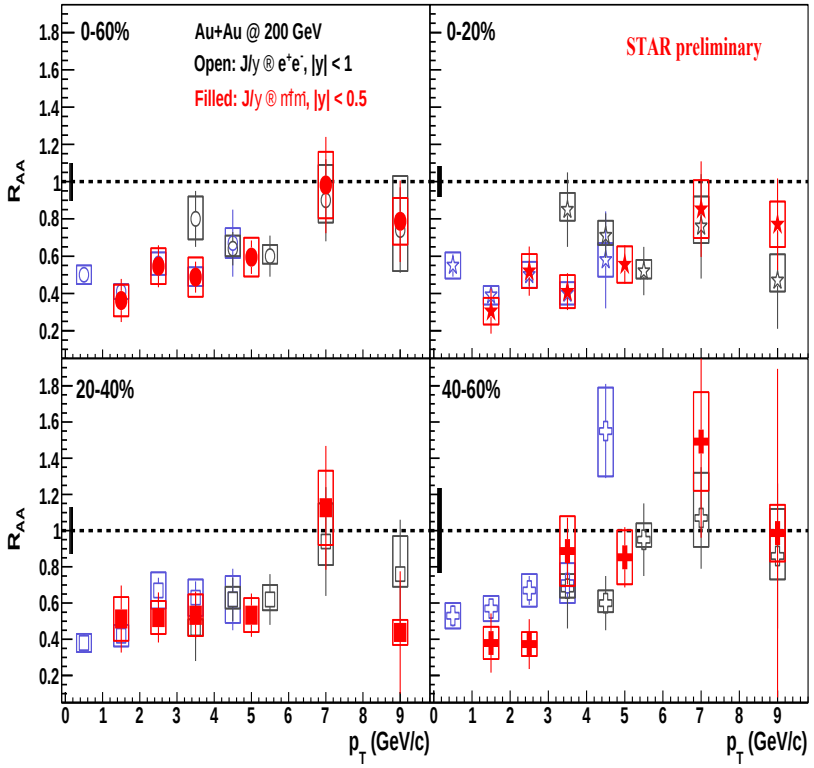


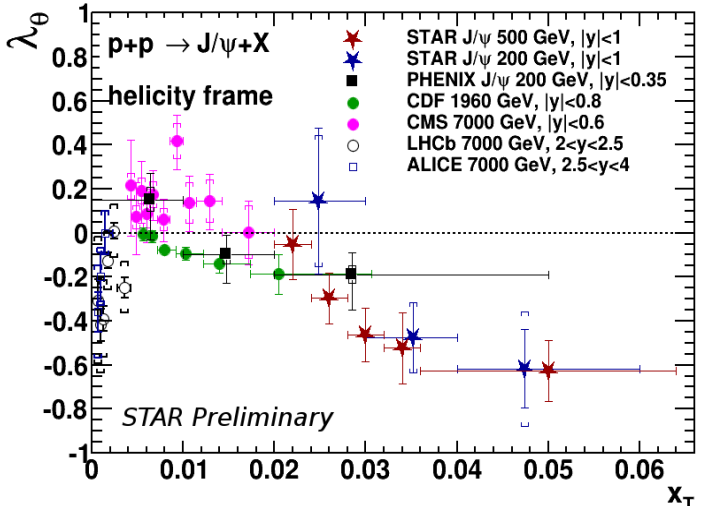


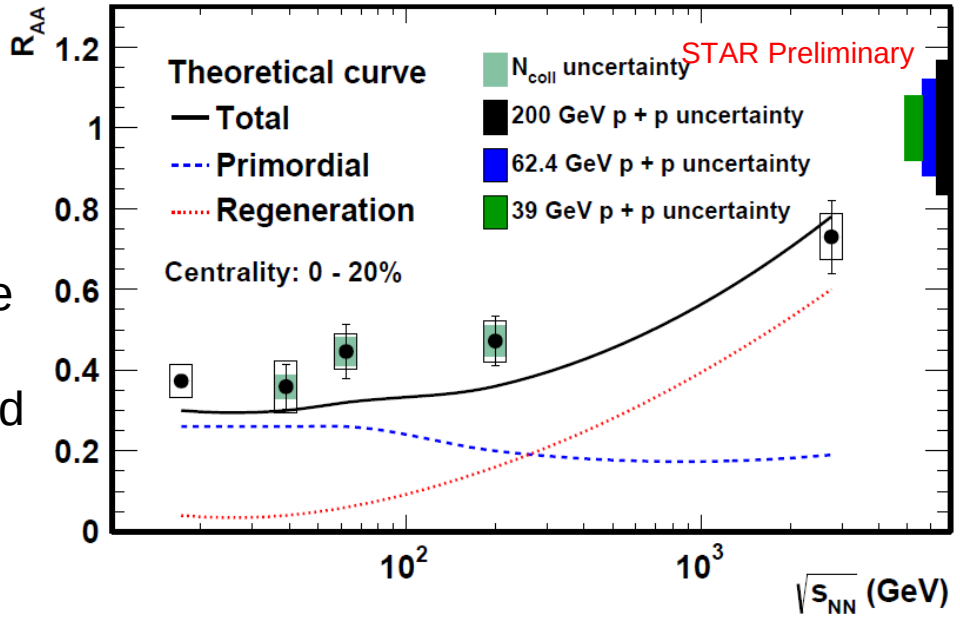


1. Reconstruction of semi-inclusive jet is successful to very low-pt using mix-event method
2. Energy loss is estimated to be ~3-5GeV for these jets; smaller than at LHC
3. Medium-induced radiation beyond 0.5 rad
4. Di-jet imbalance of Au+Au Aj similar to p+p only when low-p_T constituents are included
5. Significant broadening of h-jet correlation angle
6. No evidence for large-angle scattering of jets (maybe due to statistics)

Quarkonia production and probes

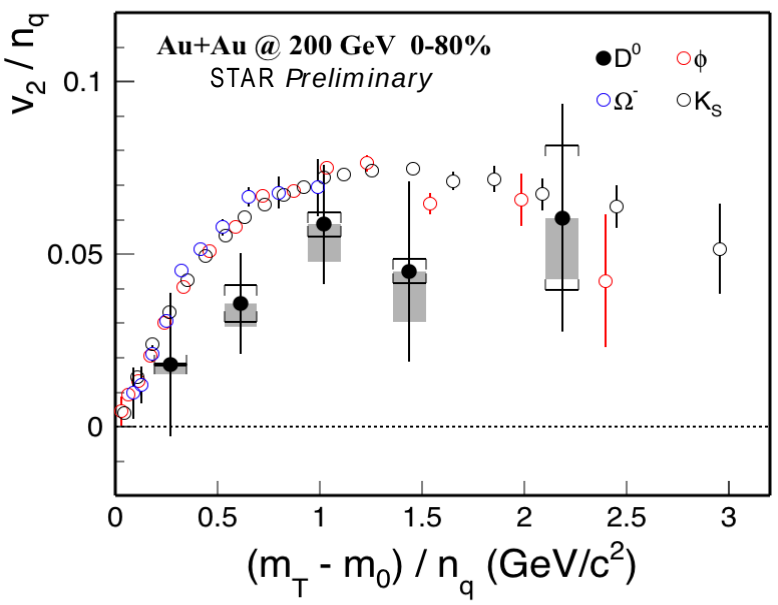


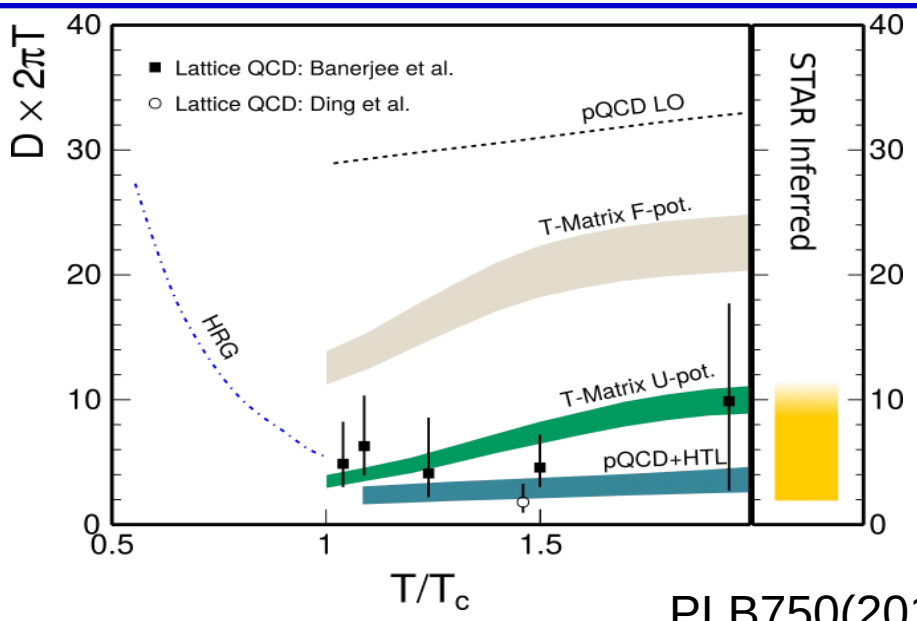




1. New MTD dataset covers whole p_T range with high statistics (x3 more data)
2. Polarization measurements in p+p extend to large X_T
3. Beam Energy dependence of J/ψ R_{AA}

(STAR QM15) Penetrating Probes





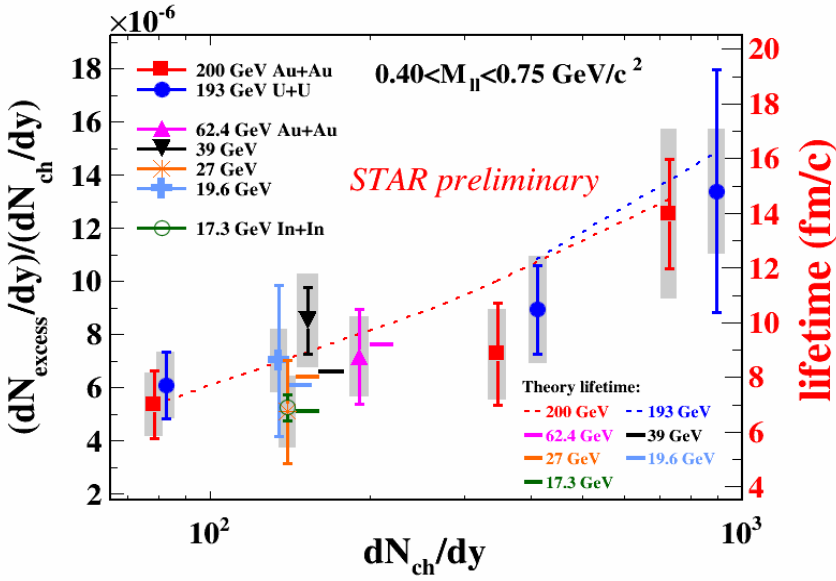
PLB750(2015)

Brownian motion (diffusion) of heavy quarks

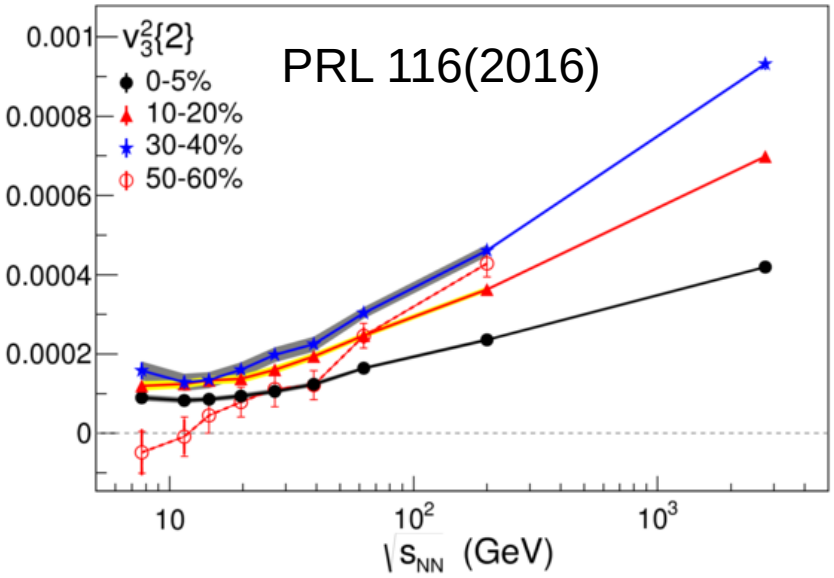
- Heavy Flavor Tracker (HFT) delivers its first results
- First result of quarkonia suppression from the Muon Telescope Detector (MTD)
- Charm flows at RHIC top energy
- Extracted diffusion coefficient compared to theory

Low-mass di-electron production

- Measured in many systems (Au+Au, U+U, p+p) and different energies (19.6, 27, 39, 62, 200 GeV)
- Quantifying how vector mesons evolve in the medium
- The yields probe timescale of collisions

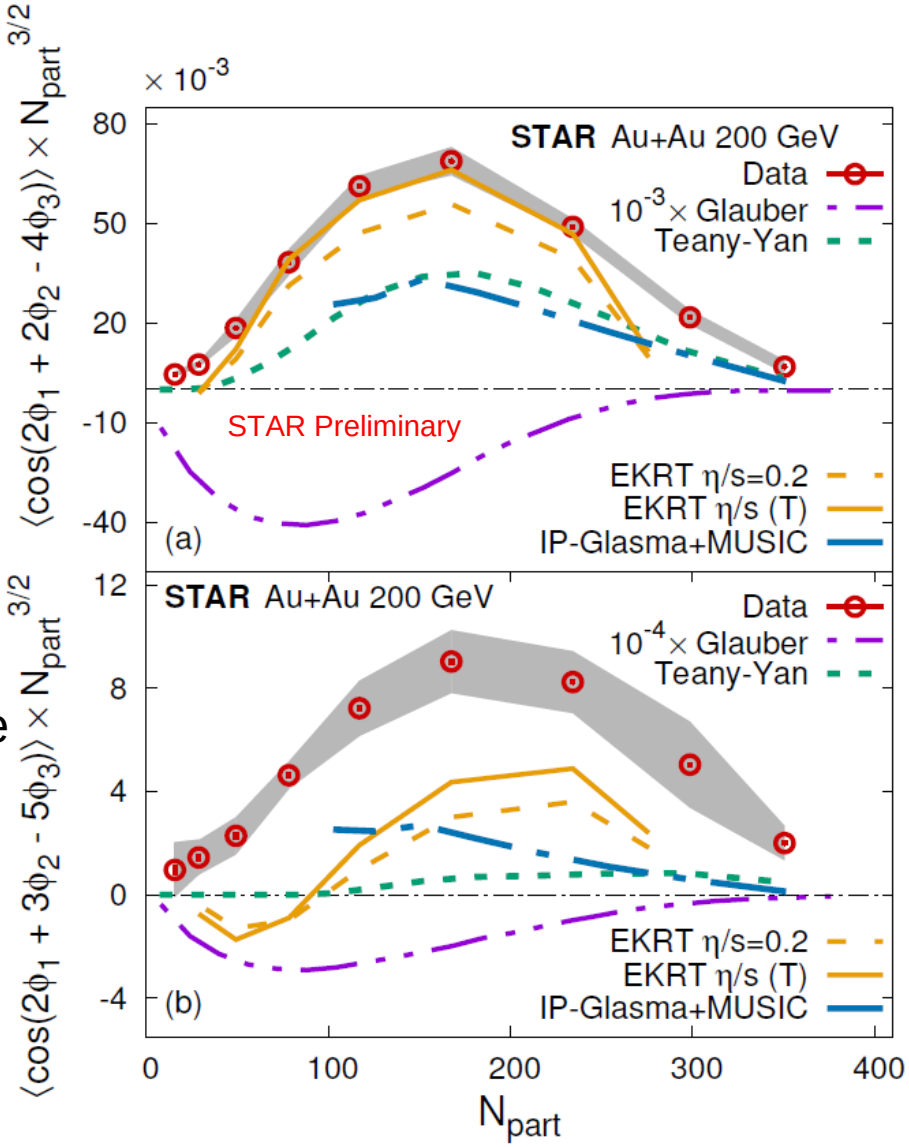


Flows in nth order



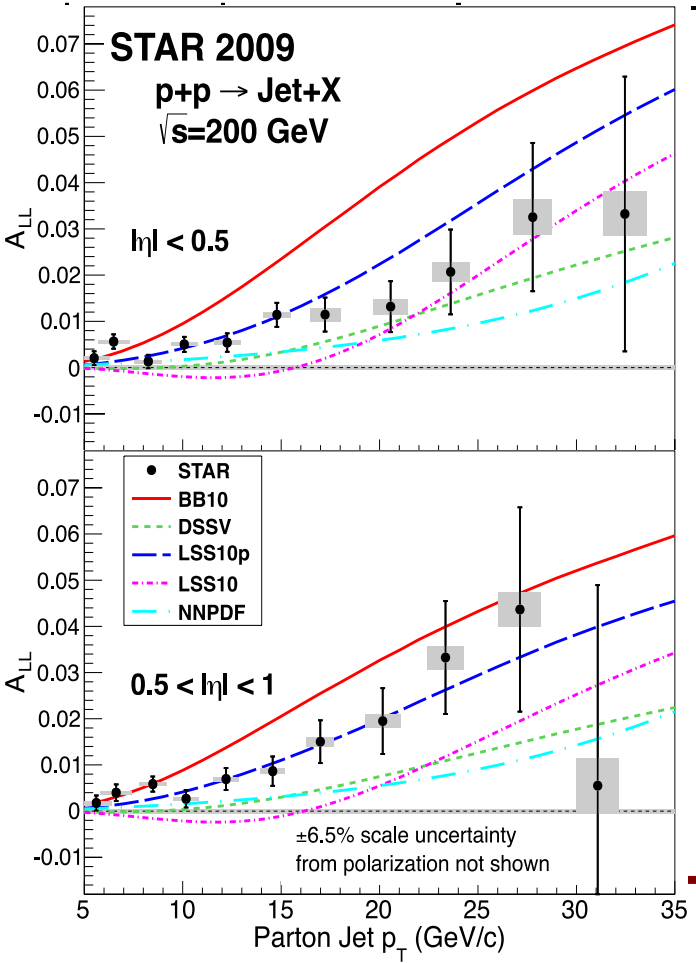
Higher harmonics sensitive to earlier stage
Study BES and small system size:
Turn OFF QGP?

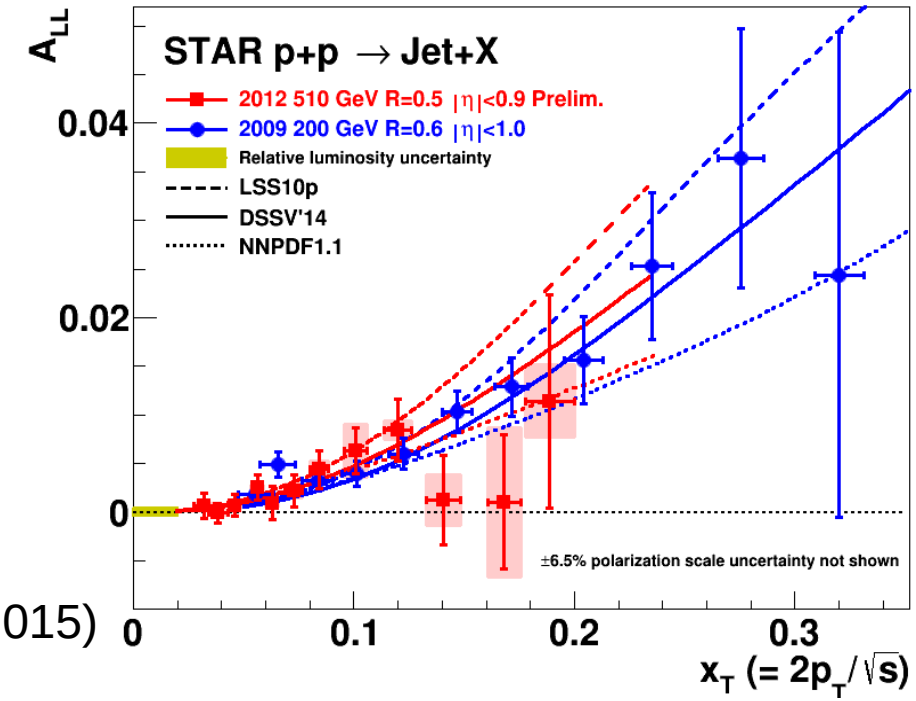
Multiple-Harmonics sensitive to η/s



NSAC Milestone (HP12)

Year	#	Milestone
2013	HP12 (update of HP1, met in 2008)	Utilize polarized proton collisions at center of mass energies of 200 and 500 GeV, in combination with global QCD analyses, to determine if gluons have appreciable polarization over any range of momentum fraction between 1 and 30% of the momentum of a polarized proton.

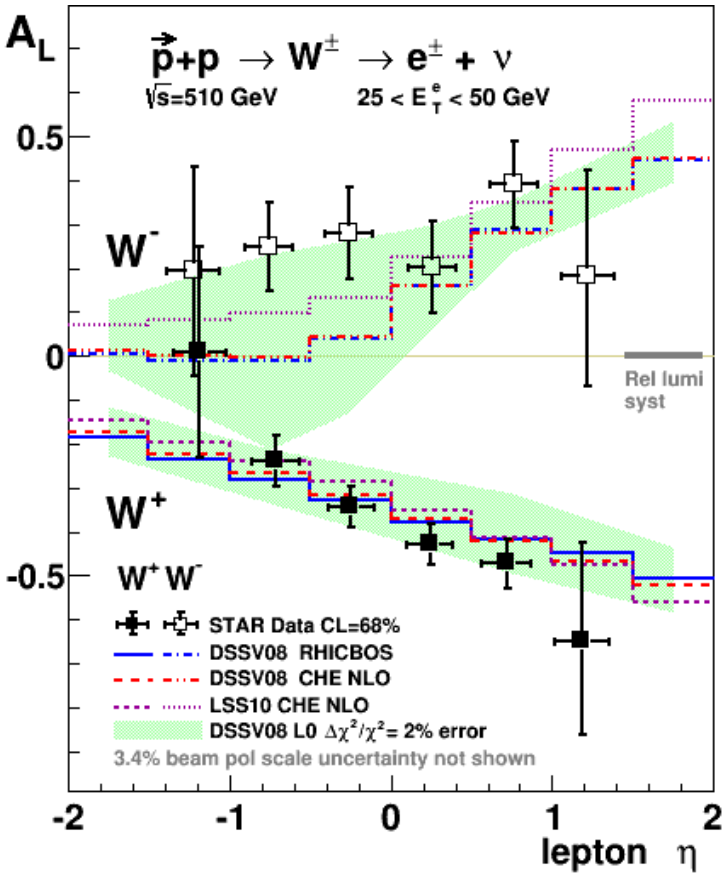


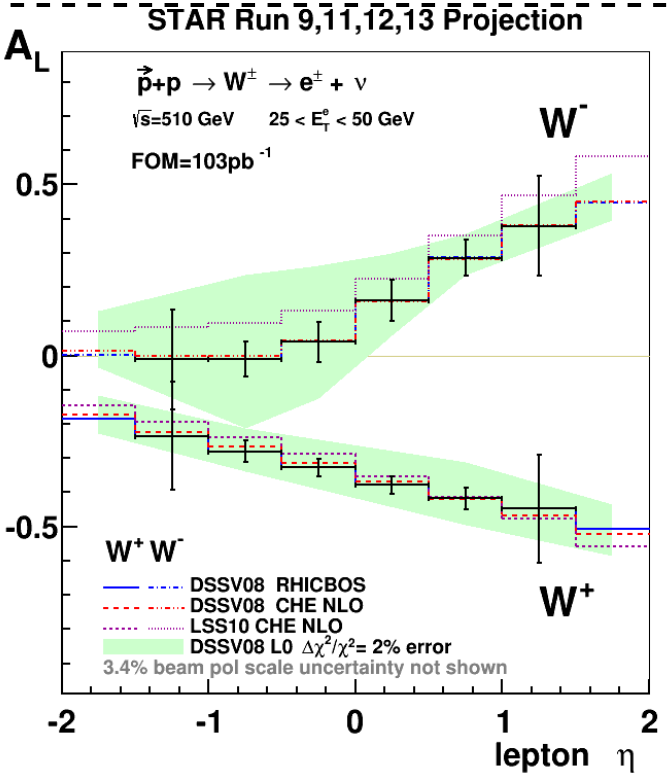


PRL 115 (2015)

NSAC Milestone (HP8)

Year	#	Milestone
2013	HP8	Measure flavor-identified q and contributions to the spin of the proton via the longitudinal-spin asymmetry of W production.





First significant evidence that u and d anti-quark spin distributions are significantly different.

PRL 113 (2014) + run13

Run 16 Heavy-Flavor Program - Completion of DM12

2016	DM12 (new)	Measure production rates, high p_T spectra, and correlations in heavy-ion collisions at $\sqrt{s_{NN}} = 200$ GeV for identified hadrons with heavy flavor valence quarks to constrain the mechanism for parton energy loss in the quark-gluon plasma.

DM12 uses the increase in RHIC luminosity that is part of the RHIC luminosity upgrade and associated detector upgrades to study rare particles with charm quarks, and possibly particles with bottom quarks, as a demanding way to learn how matter flow and energy loss are established in the partonic phase at RHIC.

Au-Au 200 GeV Highest Priority of STAR and PAC for Run-16

DOE Milestones for High Temperature/High Density Hadronic Matter
http://science.energy.gov/~/media/np/nsac/pdf/docs/perfmeasevalfinal.pdf

Run 16 proposed by STAR

Run	Energy	Duration	System	Goals	Priority	Sequence
16	$\sqrt{s_{NN}}$=200 GeV	13-wk	Au+Au	Λ_c, D v_2, R_{AA}, Υ R_{AA} 10nb^{-1},2billion MB	1	1
	$\sqrt{s_{NN}}$=19.6 GeV	1-wk	d+Au	100M MB	2	2
	$\sqrt{s_{NN}}$=39 GeV	1-wk	d+Au	400M MB	2	3

PAC recommendation of 10 weeks of Au+Au; additional 2 floating weeks

Could have reached goals: 95 hours*10wk*3600seconds*600Hz=2B
Or we could have just scaled down our goals by 30%

RHIC Machine Efficiency not Luminosity key
STAR Operation and Optimization
- key to achieving this goal.

Presented at 01/19/2016 schedule meeting

Substantial Investments to reach our BUR goals

-- Many improvements since Run14

Open Charm (HFT) related: (MB events)

- Cables: Cu => Al Cable for HFT readout: up to x2 better S/B low-p_T D^0
- Refurbished PXL and SSD firmware: ~18% PXL dead in Run-14
  SSD improves tracking 10% (20% for Ds)

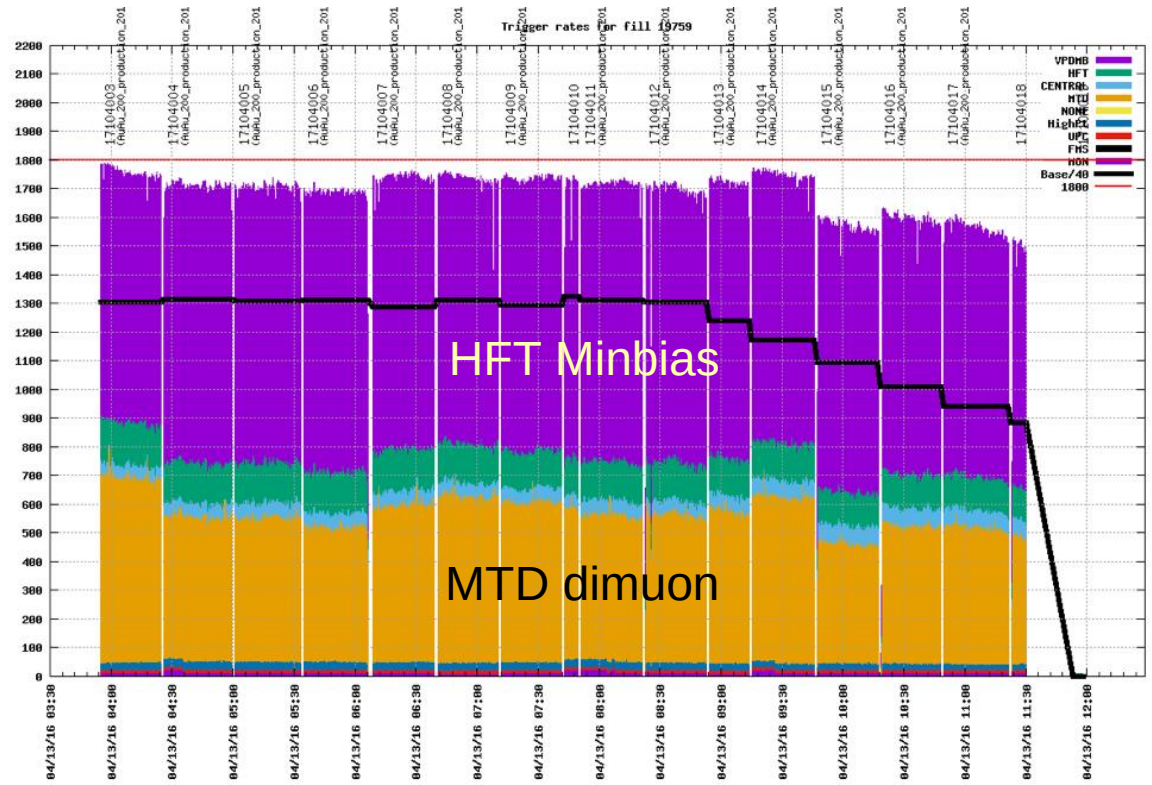
Overall factor of 3.6 improvement for D^0

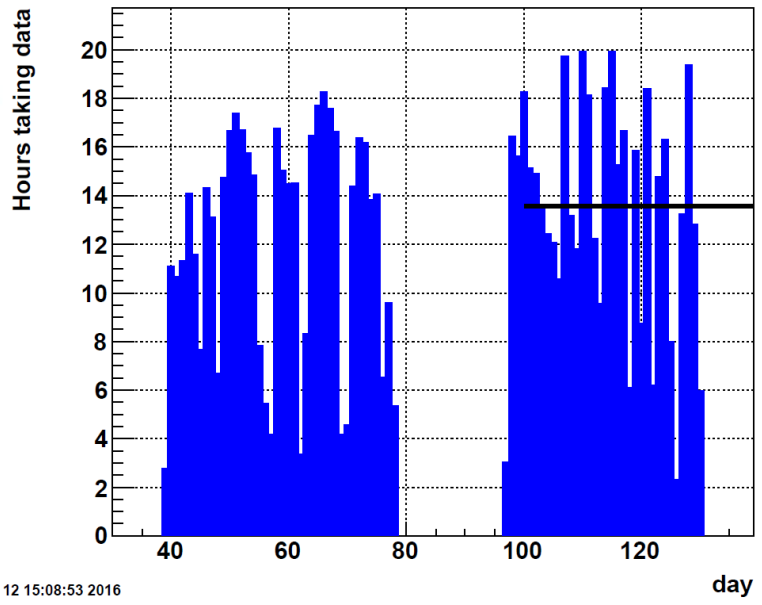
- Vertex Cut quality improvement (~15%)
- Pile-up protection study w/o 30% more data volume and 10% worse efficiency
  optimize protection (10%)
- Re-populate TPC ASIC and RDO, DAQ software optimization, online disk and network, +50% faster readout speed, reduced deadtime
- Bring up detector at RHIC Flattop and detector ramp down for beam dump
  Run 16: 7 (5) minutes vs Run 14: 9 (11) minutes

Quarkonia (MTD) related: (triggered/luminosity)

- High-Level Trigger dedicated to online dimuon selection
- Express stream of Upsilon candidates x10 reduction
- Reduce monitoring triggers to minimum required

Typical Data-taking Mode





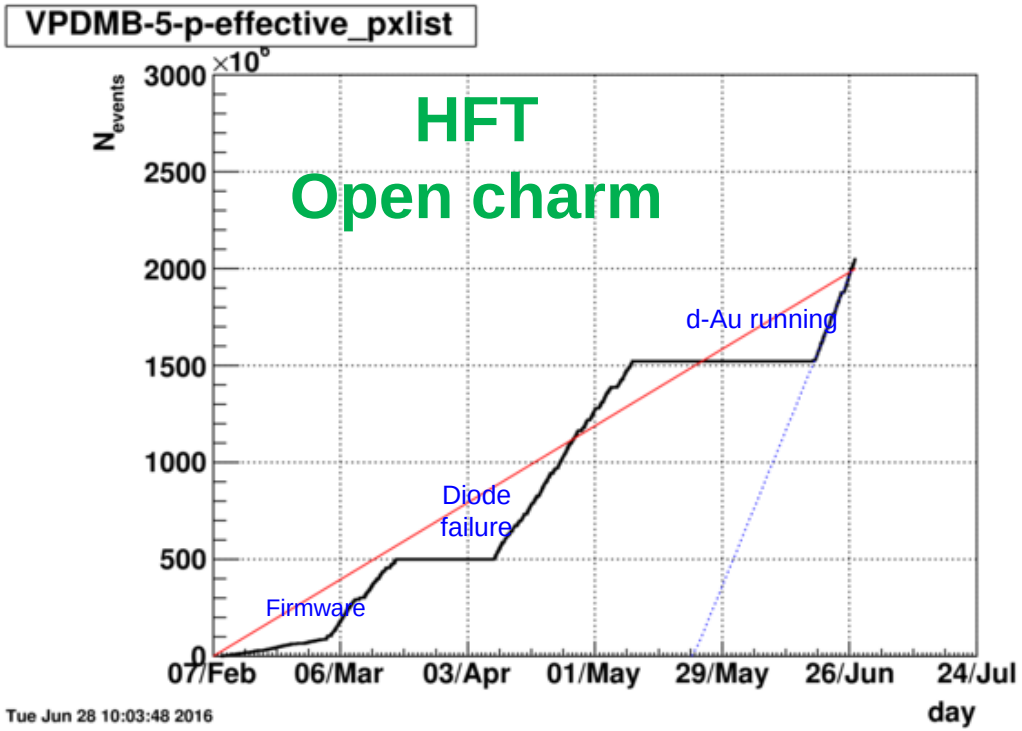
Average 13.5 DAQ hours/day

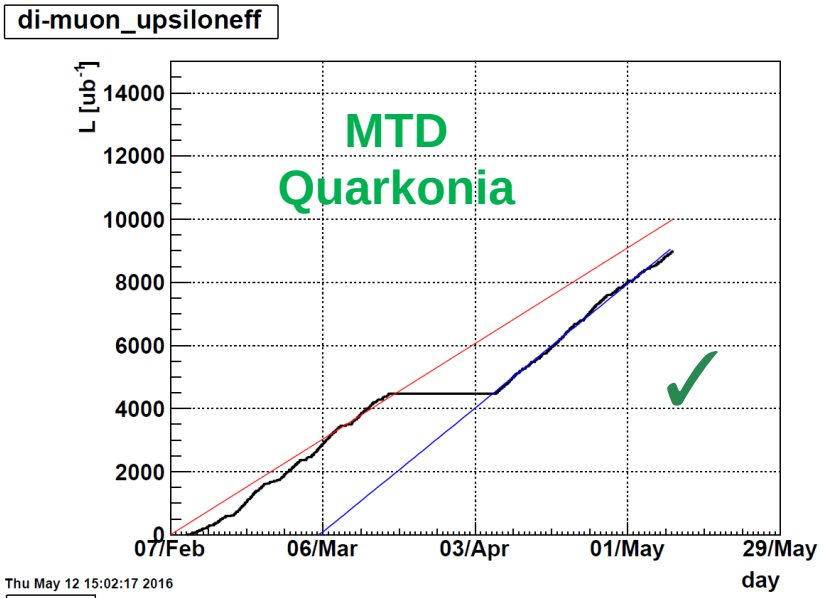
Designed and implemented by Jeff Landgraf.
Linked from Trigger versioning page
http://online.star.bnl.gov/RTS/plots/storedPlots.php

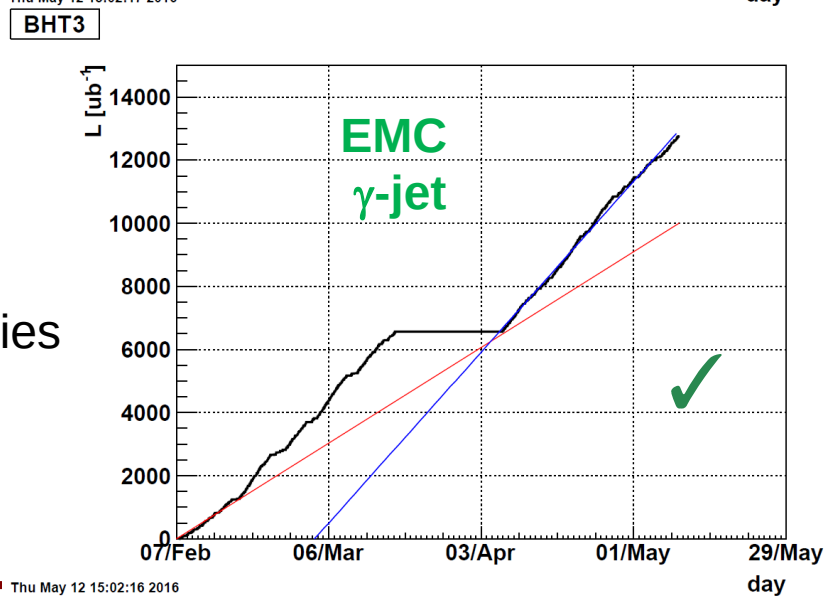
Last 4 weeks' performance:
95 hours*8.3wk*3600seconds*700Hz=2B

Excellent Machine Performance after Diode Repair

Au+Au Dataset Goals







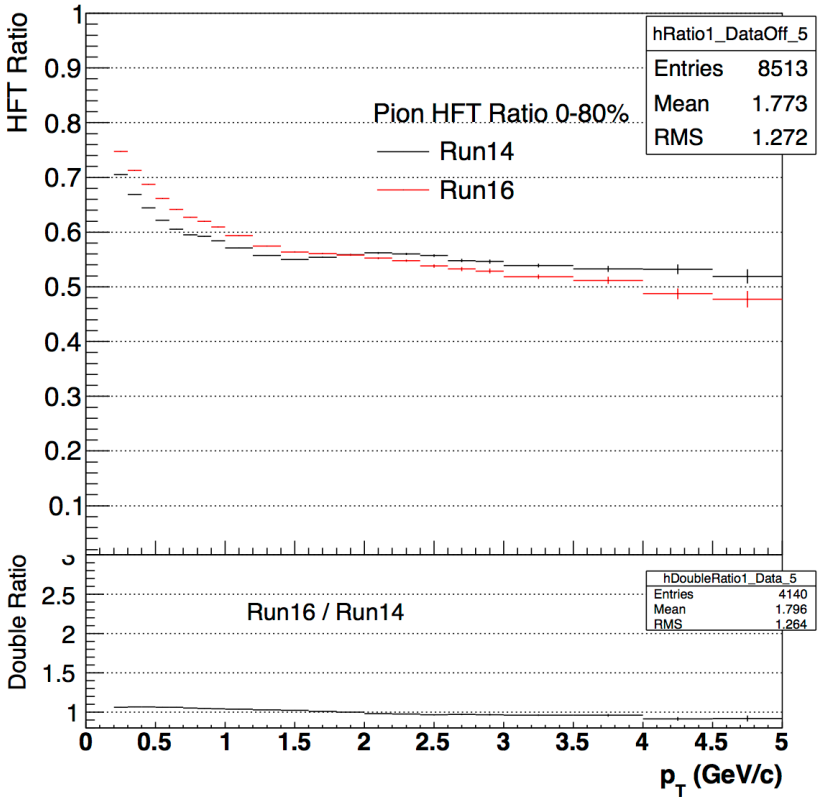
1. Minbias goal is about 103%,
2. Quarkonium (Υ) and γ-jet integrated luminosities (mostly) reach our goals.

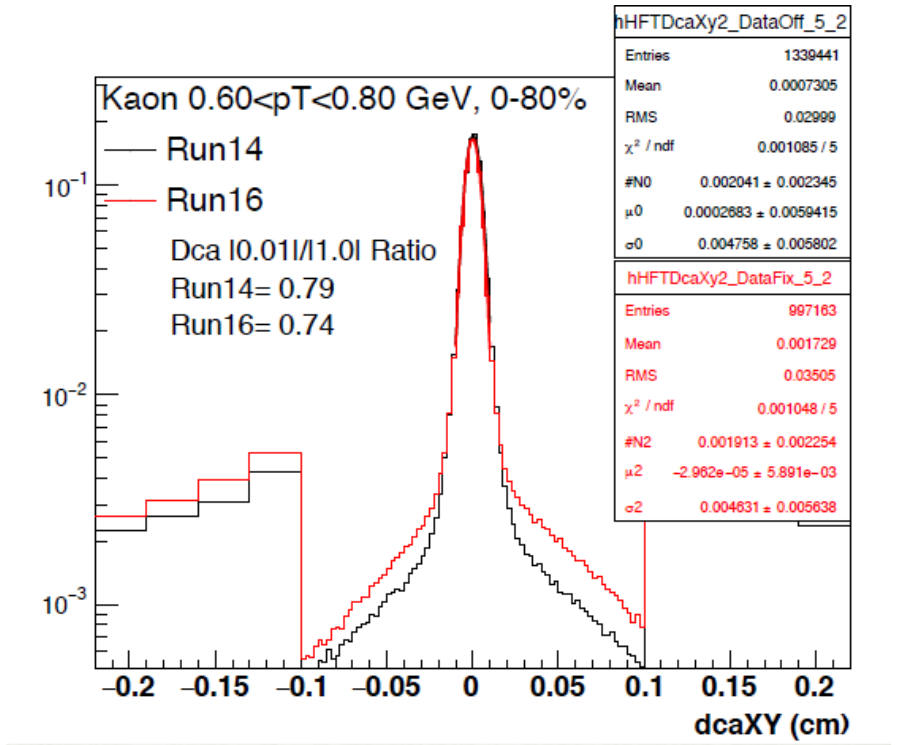
HFT Preliminary Performance (Run 16)

With preliminary calibrations, Run16 HFT matching efficiency and DCA resolution show a comparable or slightly better performance w.r.t Run14

➡ different luminosity level

➡ different trigger setup for pileup protection





Offline Physics Production

- Physics production priorities regularly reviewed and set by the joint PWGs
  with input from Software & Computing leadership

Priorities from PWGs (Fall 2015)

Top priority
- Run14 Au+Au@200GeV
  - main physics stream (HFT)

Immediate priorities (in parallel)
- Run14 Au+Au@200GeV :: MTD stream
- Run15 p+p and p+A :: FMS stream

Next priorities (no order)
- Run15 RP stream
- Run15 p+Al
- Run15 p+p and p+A heavy-ion/spin physics
- FXT for Au+Au @4.5GeV and Au+Al @4.9GeV

Modification (early 2016)
- Reproduction Run-14 Au+Au HFT stream
  - following a fix in the HFT decoding software

Prioritization 2015/16 – considerations:

Run 14 Au+Au

1. Fast-track Run-14 Au+Au at 200GeV to enable HFT publications
2. Understand MTD performance ahead of Run-16 Au+Au
3. J/ψ and Υ from MTD
   – Estimate backgrounds

Run 15 p+p

4. Input from Run-15 FMS data in p+p and p+A (FMS stream)
5. Roman Pot data sets from Run-15 p+p and p+Au (RP stream)
6. Run-15 p+p and p+Au heavy-ion/spin physics

Run 14 and 15 Production

Status

Run 14:

- ✓ Au+Au @ 14.6GeV
  - production finished Jan. '15
- ✓ Au+Au @ 200GeV
  - started: March '15
  - completed: April '16
  - includes HFT and MTD
- ✓ ^{3}He+Au @ 200GeV
  - preview production
- ☐ Au+Au @ 200GeV
  - ➢ reproduction of HFT stream
    (ongoing, currently at 30%)

Run 15:

- ✓ Fixed Target production
  - Au+Au @ 4.5GeV
  - Au+Al @ 4.9GeV
- ☐ $p+p_{trans}$ and $p+p_{long}$
  - ✓ FMS, RP streams
  - physics stream (ongoing, currently at 39%)
  - MTD stream (ongoing, currently at 71%)
- ✓ p+Au @ 200GeV
  - FMS stream
    (calibrations done)
- ☐ p+Al @ 200GeV
  - not started
    (calibrations done)

Run 16: calibrations being prepared

Production Projections

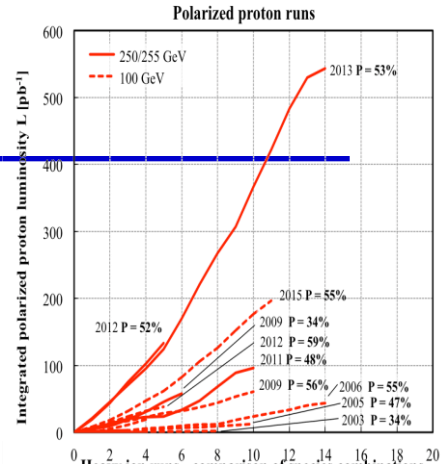
status	Dataset	Projection	Farm Occupancy
ongoing	2014 Au+Au reproduction	80 days (September 2016)	50%
	2015 pp production	50 days (August 2016)	50%
queued	2015 p+Au/p+Al	5.5 months	50%
preparing calibrations	2016 Au+Au	8 months	100% (all streams)

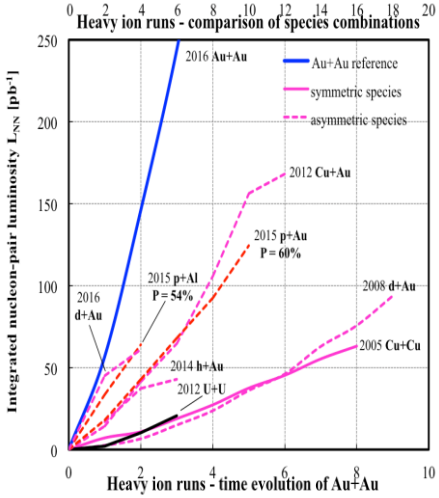
Enable parallel productions

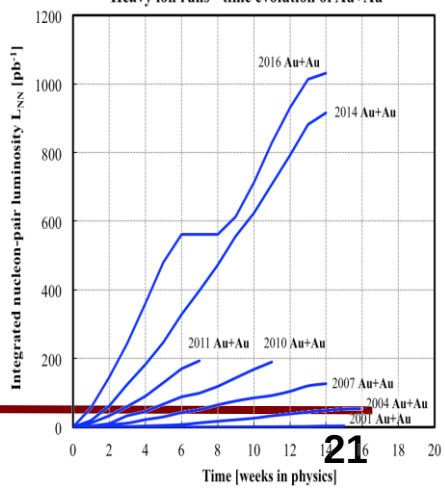
- maximimize involvement of all PWGs
- optimal usage of RHIC farm
  - (100% = 13k nodes)

Continued concern about lack of scaling of available computing resources

➢ Effort to involve other facilities (Dubna/NERSC) up to 20% impact on current projections







Postproduction Resources :: Storage

Context:

- Large and very active analyses community
- Wide variety of data sets
  - species, energies, data streams
- Significant increase in size of individual data sets
  - per run: RAW ~10PB; DST ~6PB
- No proportional growth in active storage availability at BNL
  - total distributed storage 8PB

Mitigation:

- Data Carousel: rotate datasets (staging)
- Data format: evolve from DST to MuDST
  - still reaching 6 PB/year
- PWGs move to picoDST further expand use case
  - expect reduction by ~5-10

➢ **Impact**

- timelines of physics analyses and paper prospects
- local storage at "Tier2" institutes and availability of data sets to the collaboration

	Current Usage
Data written & read per run	RAW 10PB
	DST 6 PB
I/O Bandwidth (max)	RAW 1.6 GB/sec
	DST 15 TB/day
	User 15 GB/sec
Permanent online storage (projected ~2020)	DST 8 PB (DST 20 PB)

Source: STAR Note PSN0658 – *Exascale Requirements Review for Nuclear Physics – STAR, from data taking to analysis*

BUR Executive Summary Table

Run	Energy	Duration	System	Goals	priority	Sequence
17	$\sqrt{s_{NN}}$=500 GeV	13-wk	Transverse p+p	A_N of $W^{\pm}$, γ, Drell-Yan, L=400 pb^{-1}, 55% pol	1	**1**
		1-wk	p+p	RHICf		**2**
		2-wk	CeC			
	$\sqrt{s_{NN}}$=62.4 GeV	4-wk	Au+Au	Jets, dileptons, NPE 1.5B MB	3	**3**
18	**$\sqrt{s_{NN}}$ =200 GeV**	**3.5-wk**	**Ru+Ru**	**1.2B MB**	**2**	**4**
	$\sqrt{s_{NN}}$=200 GeV	**3.5-wk**	**Zr+Zr**	**1.2B MB**	**2**	**5**
	$\sqrt{s_{NN}}$=27 GeV	**2-wk**	**Au+Au**	**>500M MB**	**3**	**6**

Options from guidance:

1) 24 cryo-weeks in run 17, 13 weeks in run 18
2) 19 cryo-weeks in run 17, 13 weeks in run 18
3) If only 15 weeks in run 17, all for pp500

Run 17 Spin Program BUR and Projections

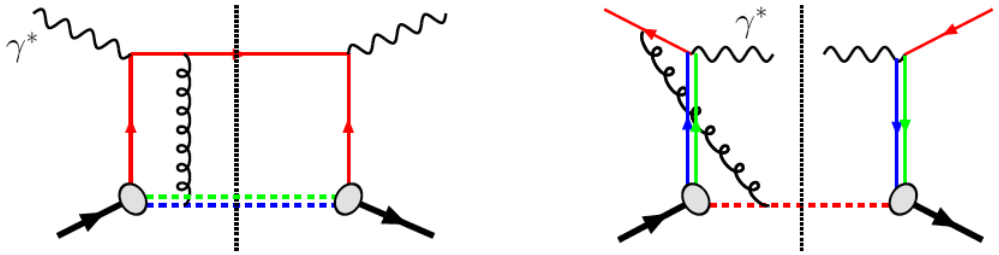
In this Beam Use Request the STAR Collaboration presents four compelling and prioritized scientific programs for the 2017 and 2018 RHIC runs.

STAR's **highest scientific priority** is the first significant measurement of the sign change of the Sivers function, as compared to the value measured in semi-inclusive deep inelastic scattering experiments, through measurements of single spin asymmetries in $W^{+/-}$, Z, direct photon and Drell-Yan production in transversely polarized $\sqrt{s}$ = 500 GeV p+p collisions. This measurement will also shed light on the size and nature of the evolution of these transverse momentum dependent distributions. The sign change measurement is a fundamental test of QCD and is being pursued by other experiments, making a timely measurement imperative. We therefore request **13 weeks of 500 GeV p+p running in Run17.**

Year	#	Milestone
2015	HP13 (new)	Test unique QCD predictions for relations between single-transverse spin phenomena in p-p scattering and those observed in deep-inelastic lepton scattering.

NSAC Milestone (HP13)

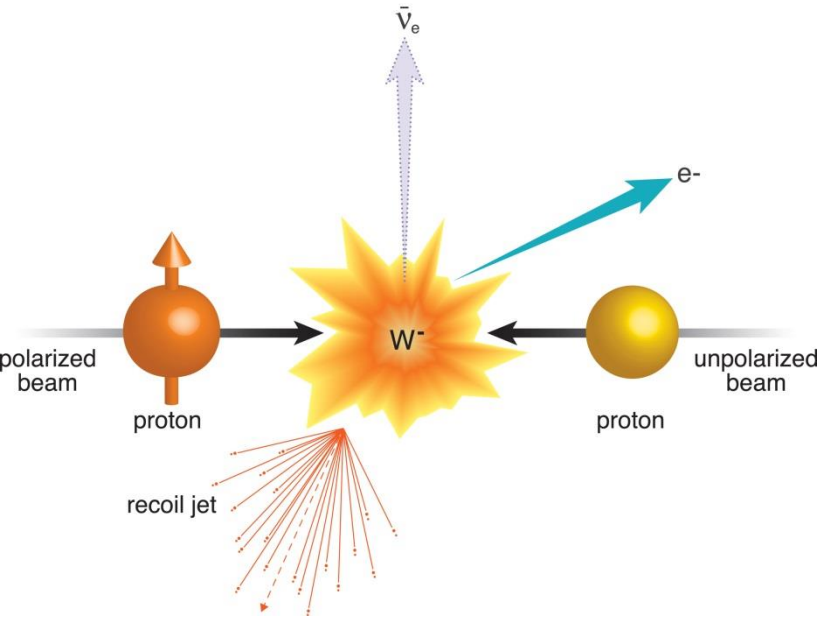
Year	#	Milestone
2013 ✓	HP8	Measure flavor-identified q and $\overline{q}$ contributions to the spin of the proton via the longitudinal-spin asymmetry of W production.
2013 ✓	HP12 (update of HP1, met in 2008)	Utilize polarized proton collisions at center of mass energies of 200 and 500 GeV, in combination with global QCD analyses, to determine if gluons have appreciable polarization over any range of momentum fraction between 1 and 30% of the momentum of a polarized proton.
2015	HP13 (new)	Test unique QCD predictions for relations between single-transverse spin phenomena in p-p scattering and those observed in deep-inelastic lepton scattering.

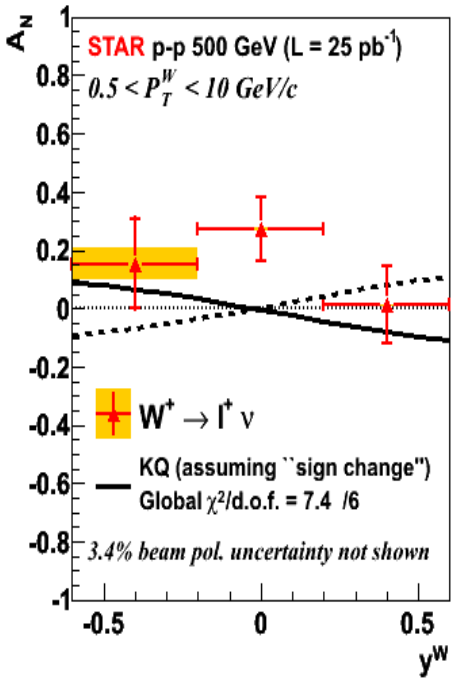


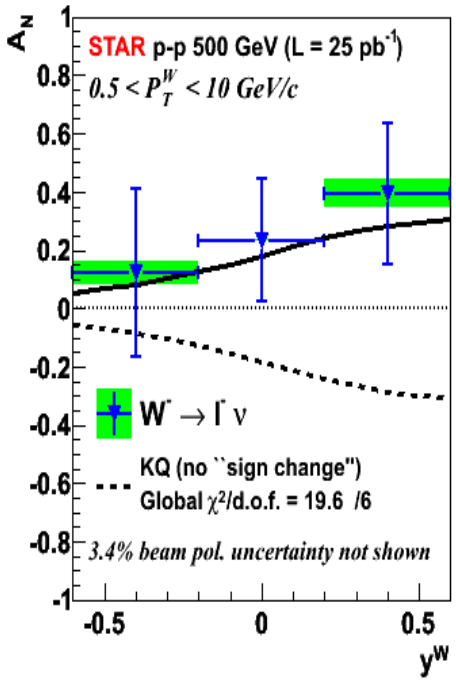
A_N of $W^{\pm}$,γ, DY in pp 500 are all sensitive to the Sivers sign-change. STAR can access all three world-class measurements in the proposed 2017 Run – **Significant discovery potential before 2020!**

Measure QCD interaction sign and TMD evolution

More in-depth discussions this afternoon:
See C. Gagliardi's talk







How to measure certain color interactions are repulsive and others attractive:
A View of the Colorful Microcosm Within a Proton (foundation for run 2017)
https://www.bnl.gov/rhic/news2/news.asp?a=1824&t=pr
STAR paper Phys. Rev. Lett. **116**, 132301 (2016), Editors' Suggestion

Summary of Sivers Function Tests Planned for STAR

	$A_N(W^{+/-},Z^0)$	$A_N(DY)$	$A_N(\gamma)$
Sensitive to Sivers fct. sign change through TMDs	Yes	Yes	No
Sensitive to Sivers fct. sign change through Twist-3 $T_{q,F}(x,x)$	No	No	Yes
Sensitive to TMD evolution	Yes	Yes	No
Sensitive to sea quark Sivers function	Yes	Yes for $x \sim 10^{-4}$	No
Detector upgrade needed	No	Yes FMS post-shower	No
Biggest experimental challenge	Integrated luminosity	Background suppression Integrated luminosity	----

Forward Detector preparation for run 17

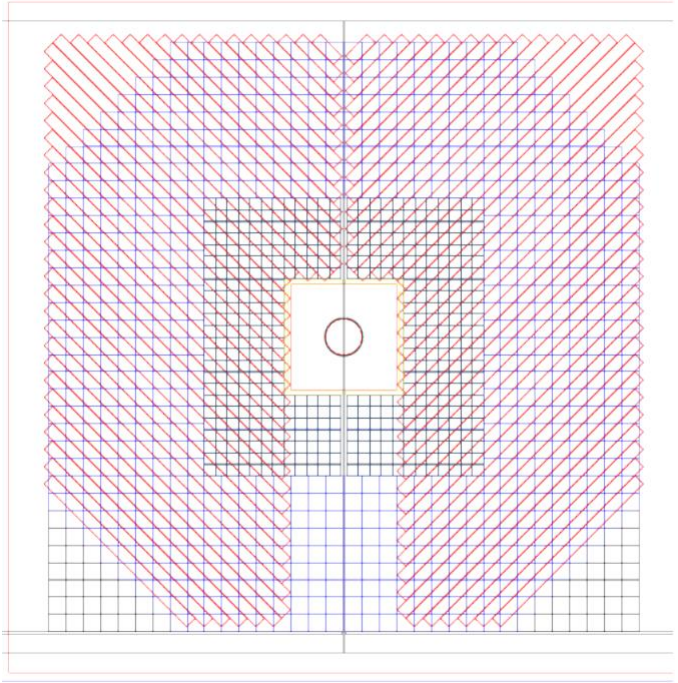
Forward Meson Spectrometer (FMS) + FMS Pre-shower + FMS Poster-Shower

Installation of pre-shower for run 15

FMS radiation cure by UV lights

1. All three detector subsystems:
   existing FMS, Pre-shower
   Add new post-shower
2. Add UV lights to cure FMS radiation

https://drupal.star.bnl.gov/STAR/system/files/STAR.FMS_.Postshower.v2.pdf

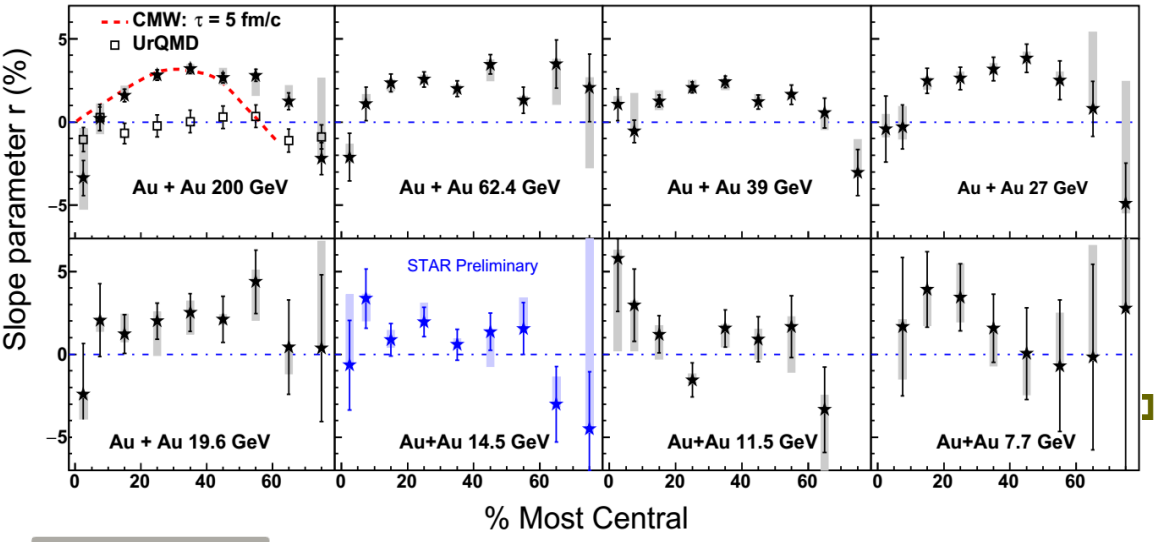


Isobar

Run	Energy	Duration	System	Goals	priority	Sequence
17	$\sqrt{s_{NN}}$=500 GeV	13-wk	Transverse p+p	A_N of $W^{\pm}$, γ, Drell-Yan, L=400 pb^{-1}, 55% pol	1	**1**
		1-wk	p+p	RHICf		**2**
		2-wk	CeC			
	$\sqrt{s_{NN}}$=62.4 GeV	4-wk	Au+Au	Jets, dileptons, NPE 1.5B MB	3	**3**
18	**$\sqrt{s_{NN}}$ =200 GeV**	**3.5-wk**	**Ru+Ru**	**1.2B MB**	**2**	**4**
	$\sqrt{s_{NN}}$=200 GeV	**3.5-wk**	**Zr+Zr**	**1.2B MB**	**2**	**5**
	$\sqrt{s_{NN}}$=27 GeV	**2-wk**	**Au+Au**	**>500M MB**	**3**	**6**

STAR's **second scientific priority** is to clarify the interpretation of measurements related to the chiral magnetic effect, chiral magnetic wave and chiral vortical effect. We therefore request **two 3.5 week runs in Run 18** with collisions of isobaric nuclei, Ruthenium-96 (Ru+Ru) and Zirconium-96 (Zr+Zr). Ru nuclei have an atomic charge of 44 compared to 40 for Zr. Ru+Ru collisions will therefore generate a magnetic field approximately 10% larger than Zr+Zr collisions while all else remains virtually fixed. Comparisons of charge separation in Ru+Ru and Zr+Zr collisions will isolate the magnetic field dependence of the observed charge separation thereby determining what fraction of those measurements are related to the chiral magnetic effect. These results will greatly advance our understanding of the chiral magnetic effect and have fundamental impact beyond the field of high-temperature QCD.

Results from Chiral Effects

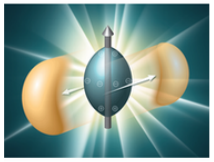


Editors' Suggestion

Observation of Charge Asymmetry Dependence of Pion Elliptic Flow and the Possible Chiral Magnetic Wave in Heavy-Ion Collisions

L. Adamczyk *et al.* (STAR Collaboration)

Phys. Rev. Lett. **114**, 252302 (2015) – Published 26 June 2015



A possible signature of chiral symmetry restoration, in the form of a chiral magnetic wave in the quark-gluon plasma, has been observed in heavy-ion collisions at RHIC.

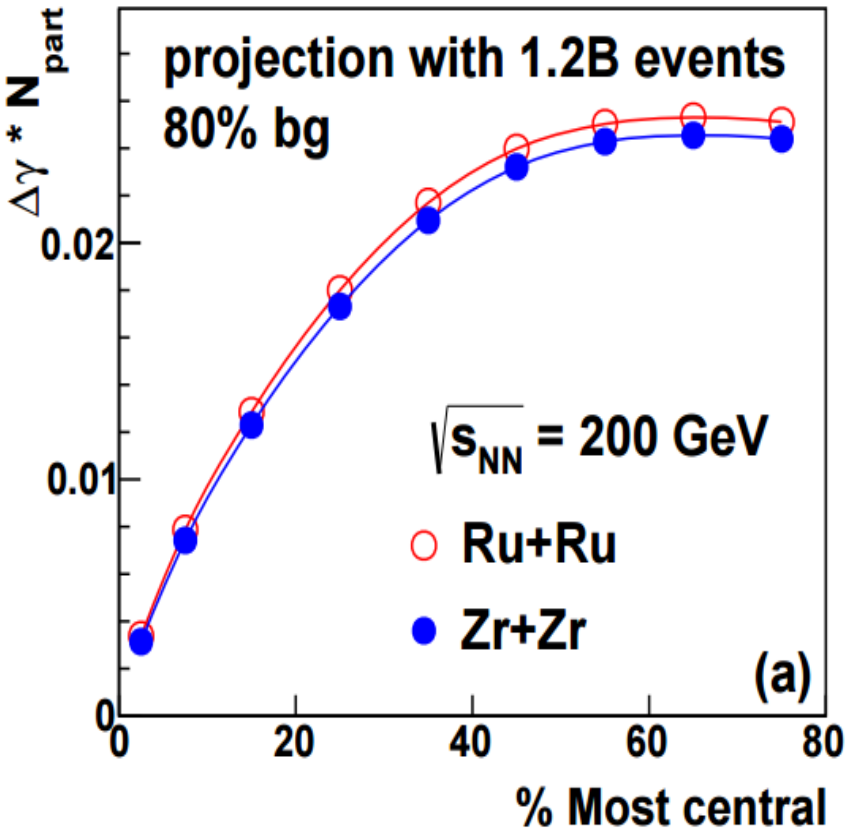
Show Abstract +

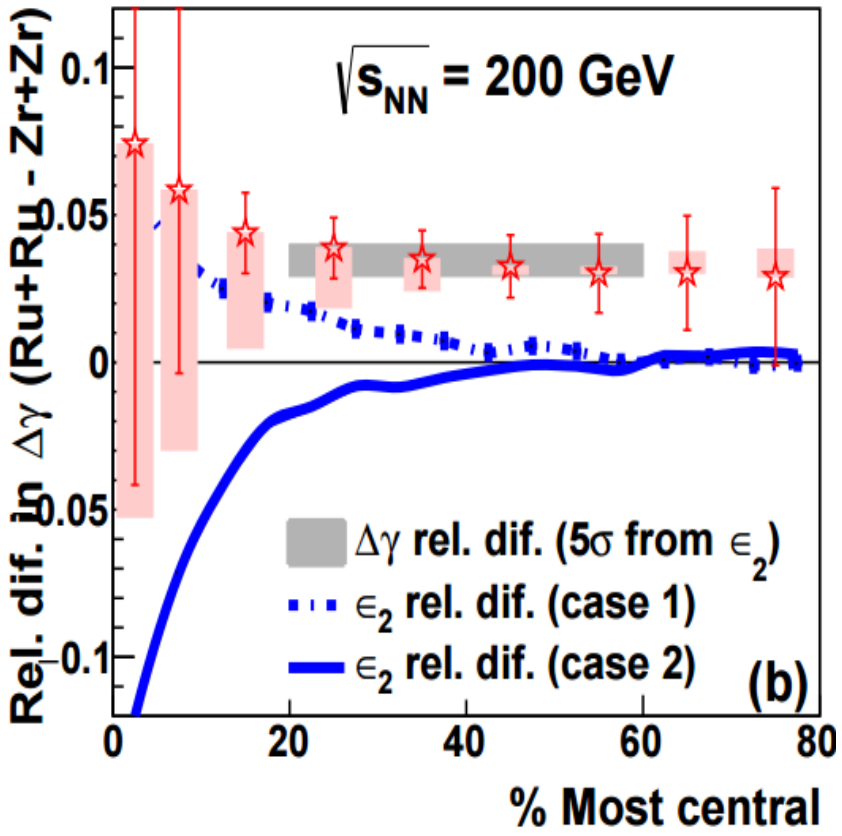
PRL on possible Chiral Magnetic Wave

More in-depth discussions this afternoon:
Talk by Paul Sorensen from CME Task Force

- We have published a few papers on possible Chiral Magnetic Effect and potential background
- U+U collisions
  Better understanding
- BES-I results on CME
  14.5GeV
- BES II with more statistics
- Chiral Magnetic Wave
  14.5GeV
- Chiral Vortical Effect

A decisive test with Isobars

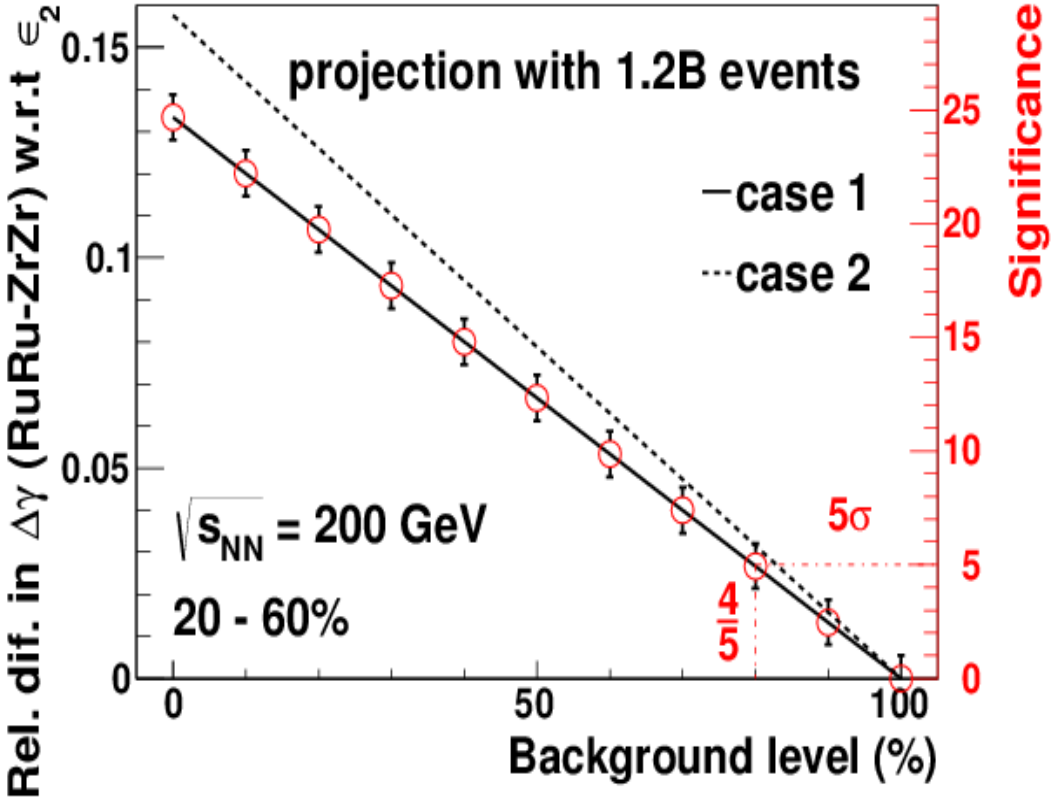


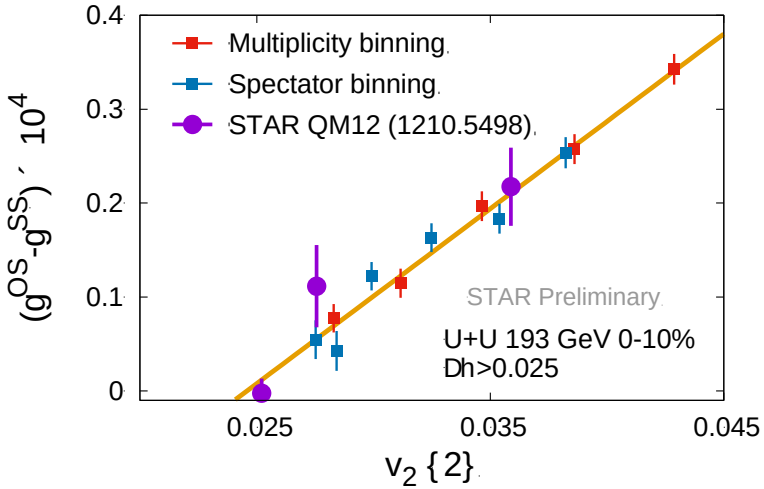


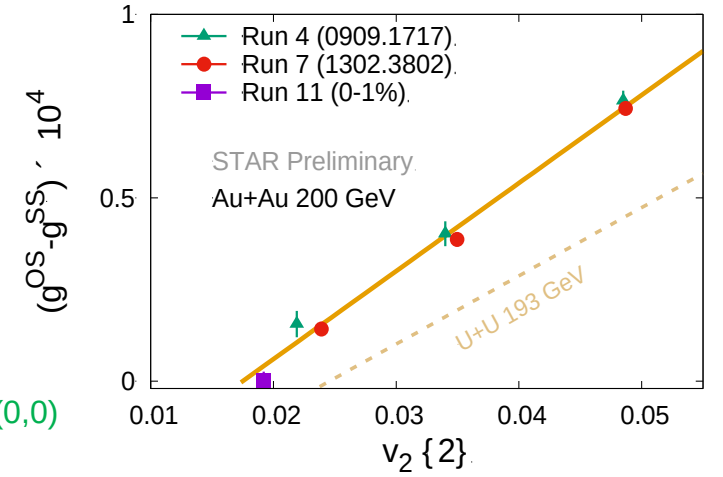
CAD was not able to locate enriched Ruthenium-96 source
Possible with the refurbished Oakridge Isotope Facility,
Run with natural abundance reduces luminosity by x5
Can reach 1.2 Billion events within 3.5 weeks of operation

Projections for Isobar

With 1.2B minbias events each species
5σ significance
if 80% observed correlation is background







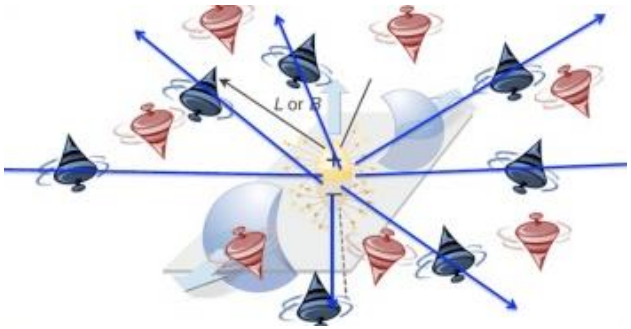
Au+Au at 27GeV

Run	Energy	Duration	System	Goals	priority	Sequence
17	$\sqrt{s_{NN}}$=500 GeV	13-wk	Transverse p+p	A_N of $W^{\pm}$, γ, Drell-Yan, L=400 pb^{-1}, 55% pol	1	**1**
		1-wk	p+p	RHICf		**2**
		2-wk	CeC			
	$\sqrt{s_{NN}}$=62.4 GeV	4-wk	Au+Au	Jets, dileptons, NPE 1.5B MB	3	**3**
18	**$\sqrt{s_{NN}}$ =200 GeV**	**3.5-wk**	**Ru+Ru**	**1.2B MB**	**2**	**4**
	$\sqrt{s_{NN}}$=200 GeV	**3.5-wk**	**Zr+Zr**	**1.2B MB**	**2**	**5**
	$\sqrt{s_{NN}}$=27 GeV	**2-wk**	**Au+Au**	**>500M MB**	**3**	**6**

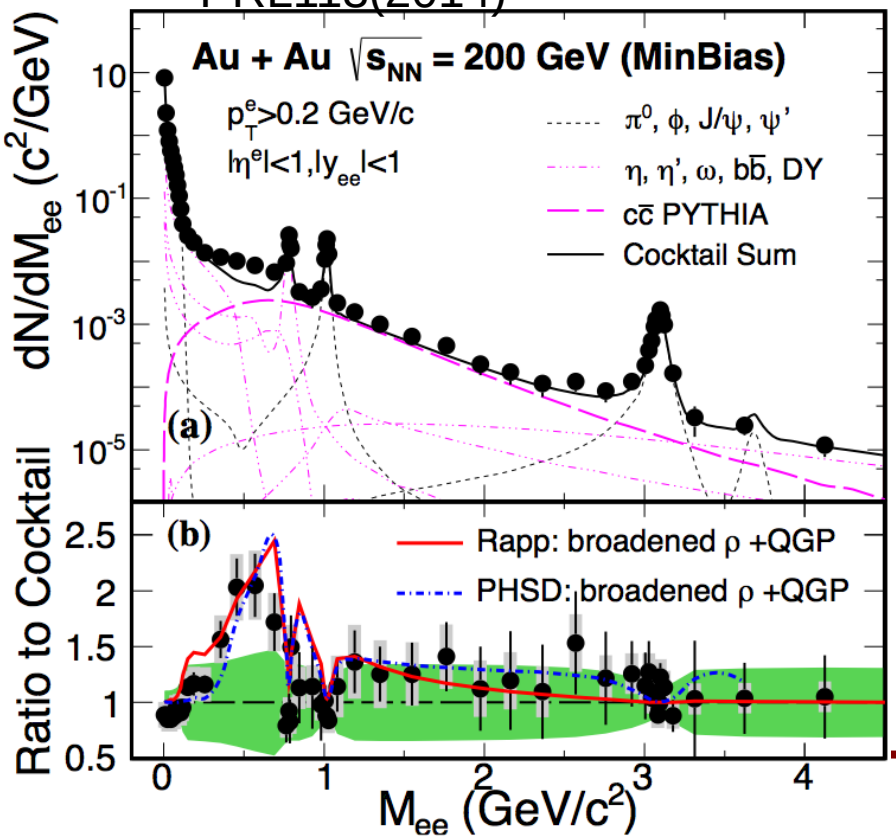
The second request is derived from STAR's recent report of the observation of the *global* polarization of hyperons (GPH) in non-central Au+Au collisions at energies below 40GeV. This is the first direct probe of the plasma vorticity, a fundamental characteristic of any fluid that must be quantified in ordrer to understand the physics in detail. It also provides a measure of the magnetic field present over the evolution of the QGP. In addition to being of fundamental interest on their own accounts, these measurements provide critical context for recent high-profile studies of exotic phenomenon. In

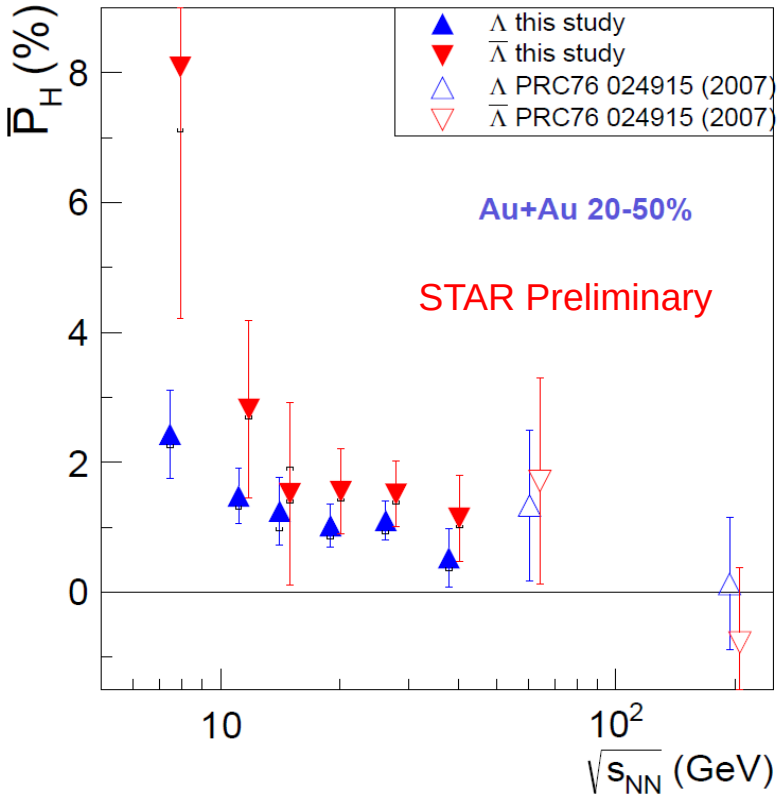
QCD phase transition is a chiral phase transition

1. Charge separation (14.5GeV)
2. Bulk charge dependence of $\pi^{\pm}$ v_2
3. Low-mass dilepton excess
4. Global polarization of hyperons



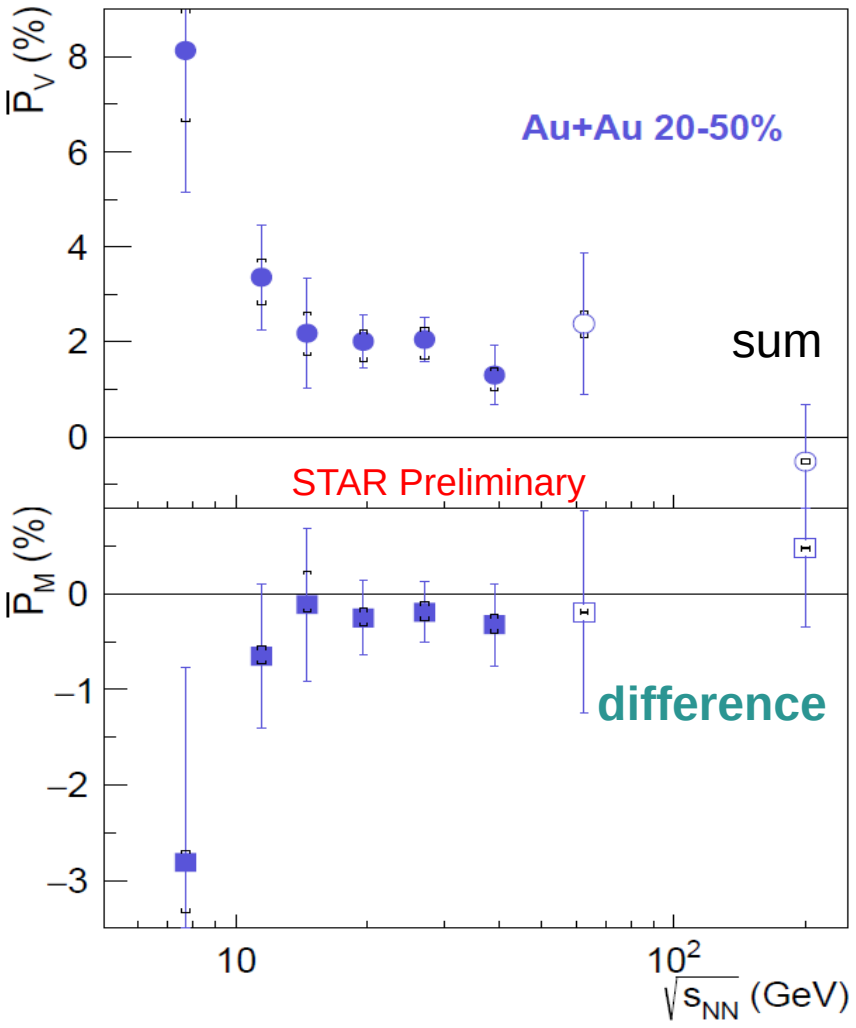
PRL113(2014)





QCD fluid responds to external field

- Current data not able to distinguish Lambda/AntiLambda polarization difference,
- (potentially) Direct measure of Magnetic Field effect
- **Need >x10 more data**

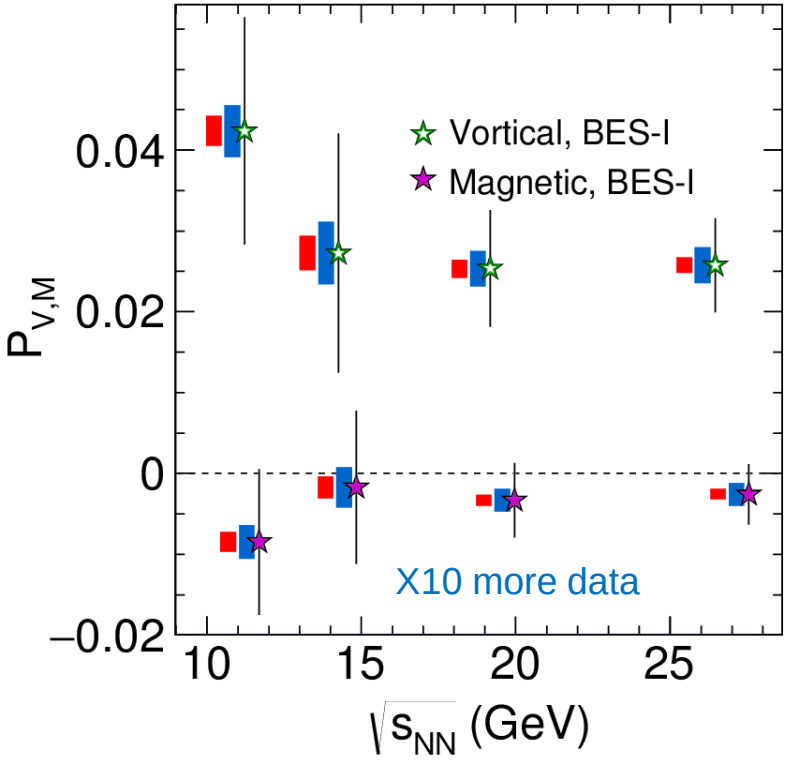


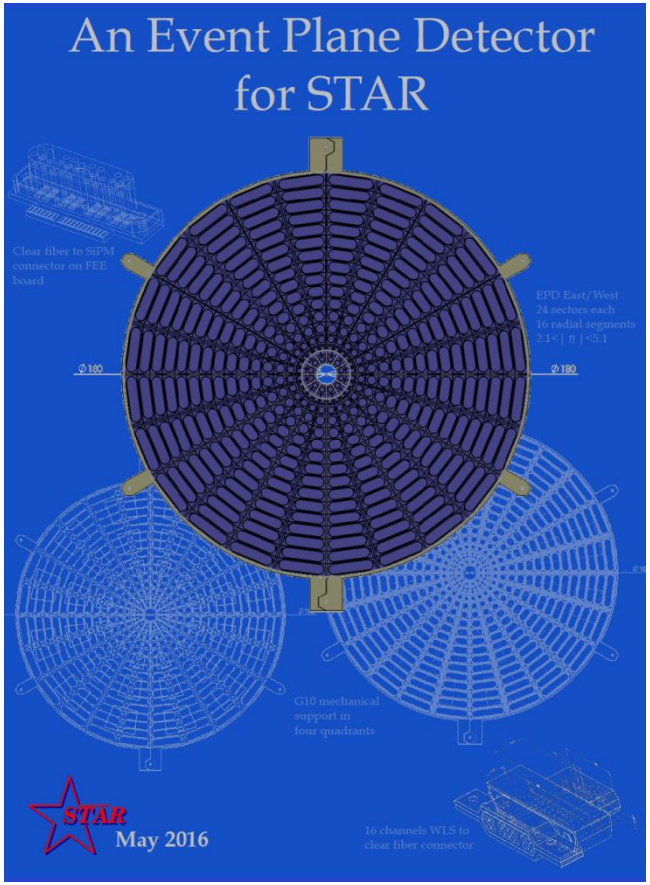
RHIC/AGS Users Meeting:
June 7 Xin-Nian Wang Polarization of Fermions in Vorticular Field
June 8 Issal Upsal Lambda Global Polarization

Request Au+Au 27GeV in run18 with EPD

https://drupal.star.bnl.gov/STAR/system/files/EPD_Construction_Proposal.pdf

- Clearly, very exciting development
- Signal and BES dependence need more data
- Request Au+Au 27GeV in run 18 with EPD or run17 without EPD, but earlier results
- To establish whether there is a difference
- Result will guide further studies in BES-II





Highlights of BES-II and Upgrades in LRP 2015

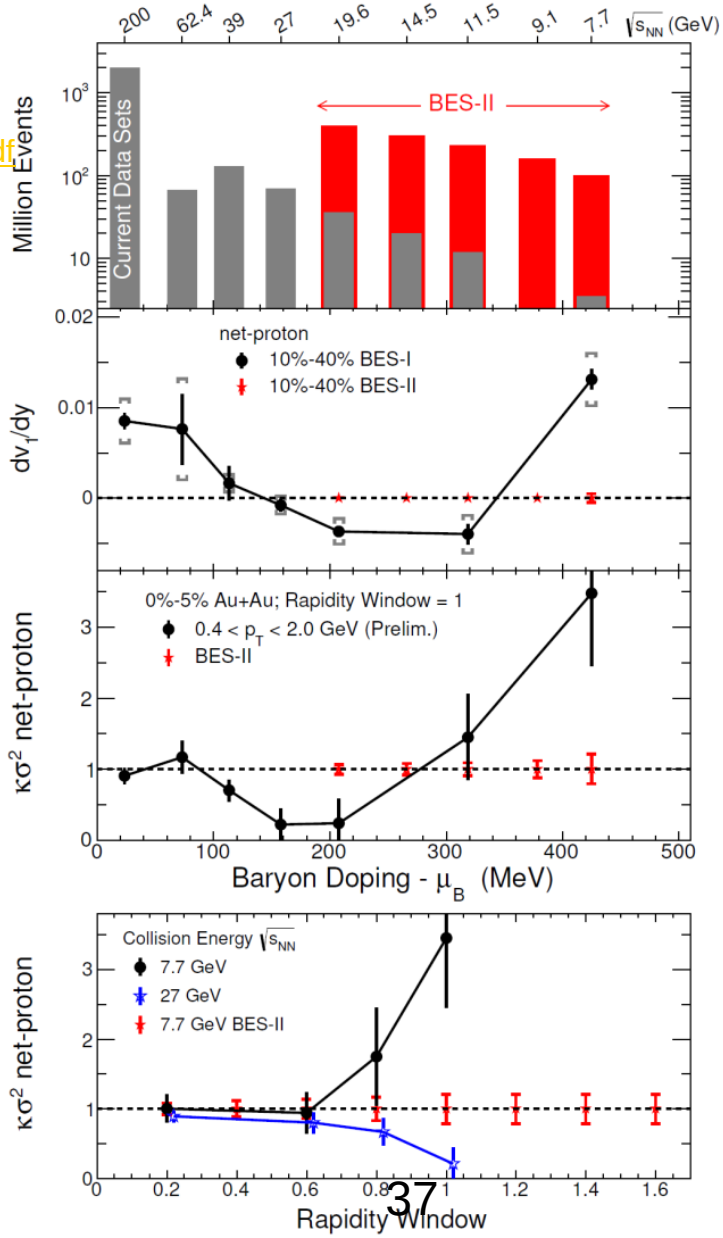
Strong Endorsement by the NSAC 2015

http://science.energy.gov/~/media/np/nsac/pdf/2015LRP/2015_LRPNS_091815.pdf

Data from BES-I provide qualitative evidence for a reduction in the QGP pressure, with consequences for flow patterns and droplet lifetimes that have long been anticipated in collisions that form QGP not far above the crossover region. (See second panel of Figure 2.10.)

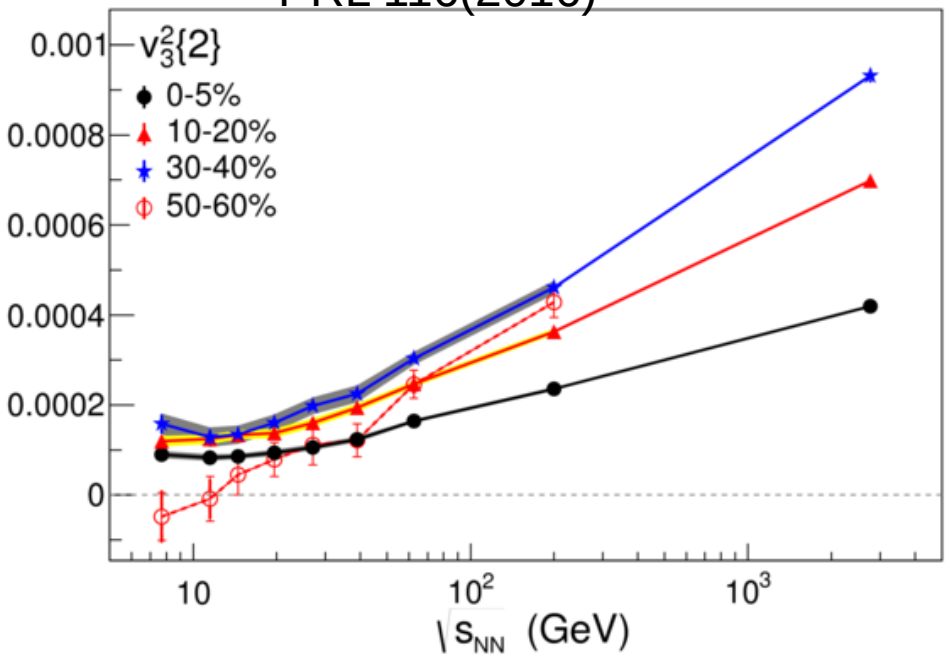
The detector upgrades planned for BES-II focus on maximizing the fraction of the particles in each collision that are measured, which is particularly important for fluctuation observables.

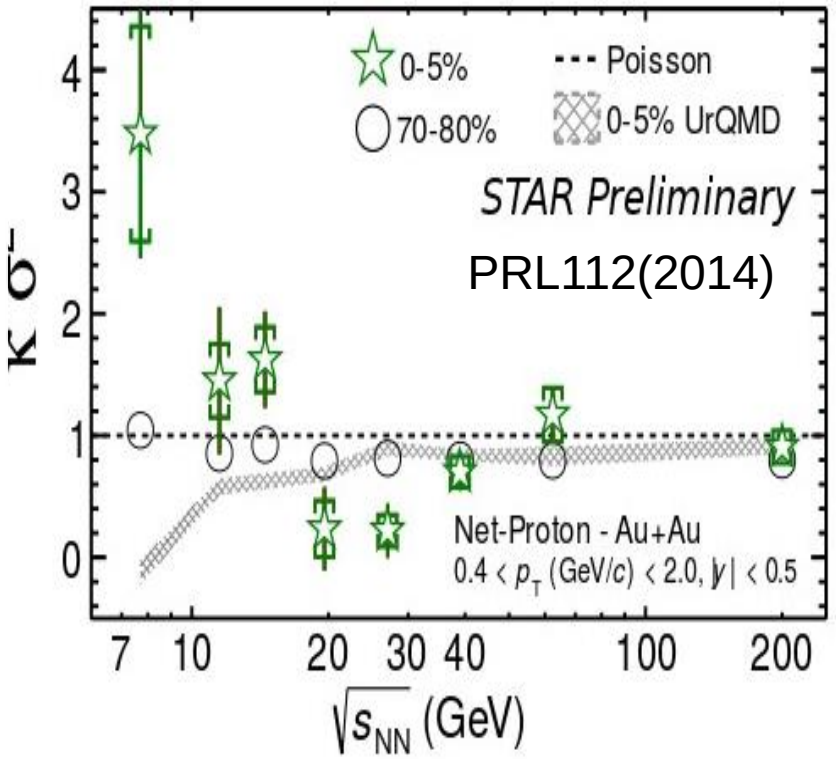
The trends and features in BES-I data provide compelling motivation for a strong and concerted theoretical response, as well as for the experimental measurements with higher statistical precision from BES-II. The goal of BES-II is to turn trends and features into definitive conclusions and new understanding.



(STAR) Map QCD phase diagram (I)

PRL 116(2016)



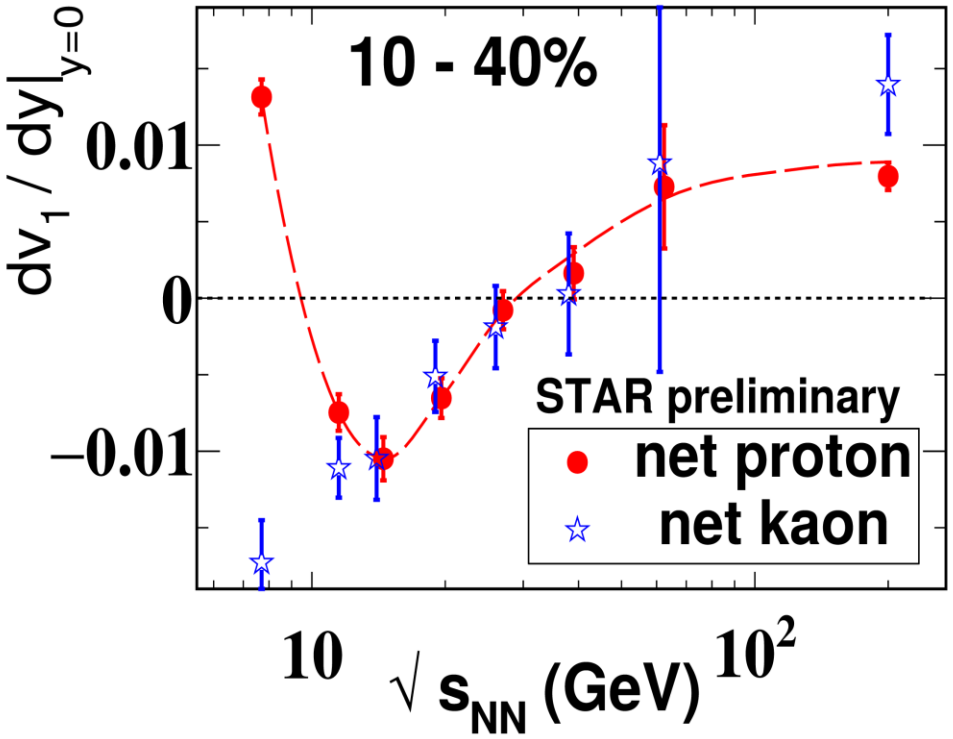


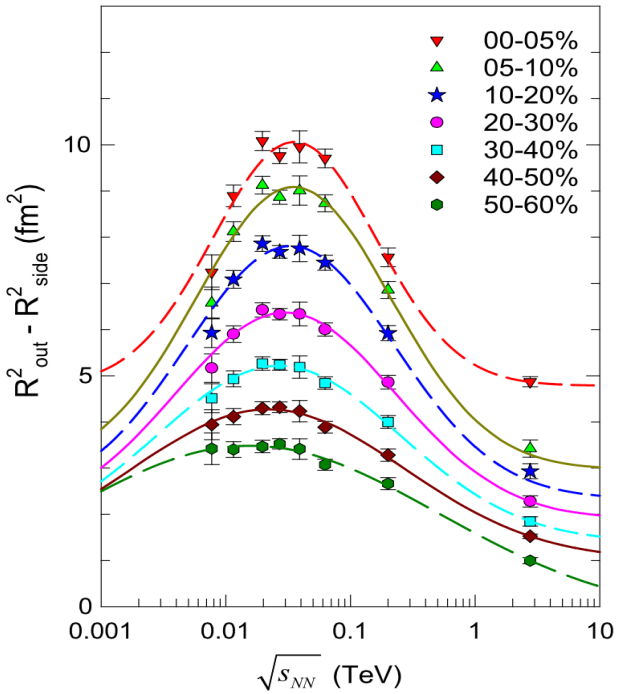
Beam Energy Scan Program:

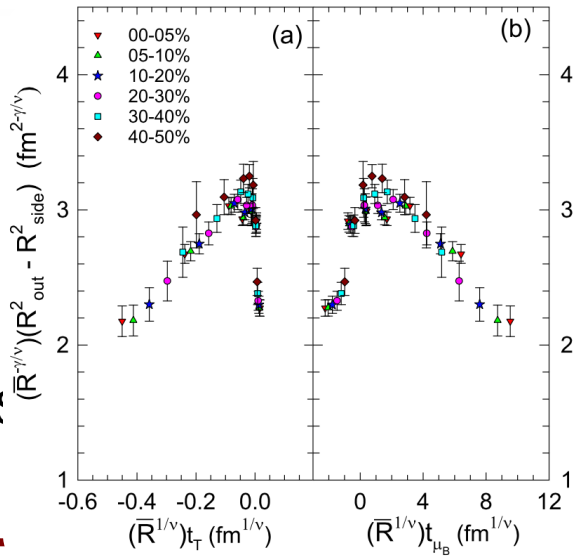
- Turn off QGP Signatures
  triangle flow (v_3) in peripheral at low energy consistent with zero
  Hadron suppression at high p_T
- Search for critical point
  net-proton Kurtosis possibly not Poissonian and grow with accepted rapidity window
- AND…

(STAR) Map QCD phase diagram (II)

PRL112(2014)







Beam Energy Scan Program:

- …

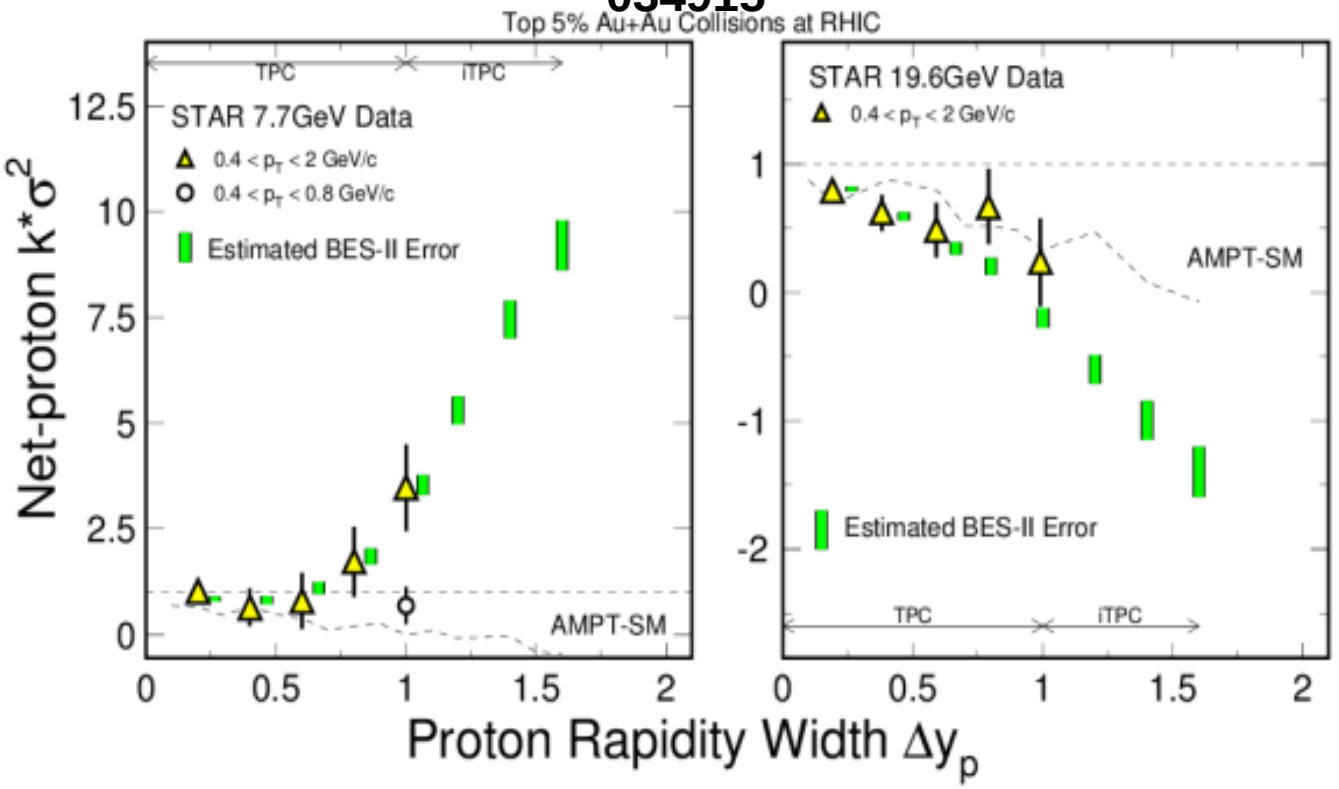
- Search for first-order phase transition
  - minimum net-proton v1 slope from interplay between baryon stopping and soft EOS
  - Finite Size (HBT) Scaling shows Criticality compressibility, speed of sound?

R. Lacey, PRL **114**, 142301 (April 2015)
STAR, PRC92(2015)

Detector Upgrades necessary for net-proton Kurtosis

Reach the necessary rapidity width of the correlation/fluctuation (~1-2 unit)

B. Ling and M. Stephenaov, Phys.Rev. C93 (2016) 034915



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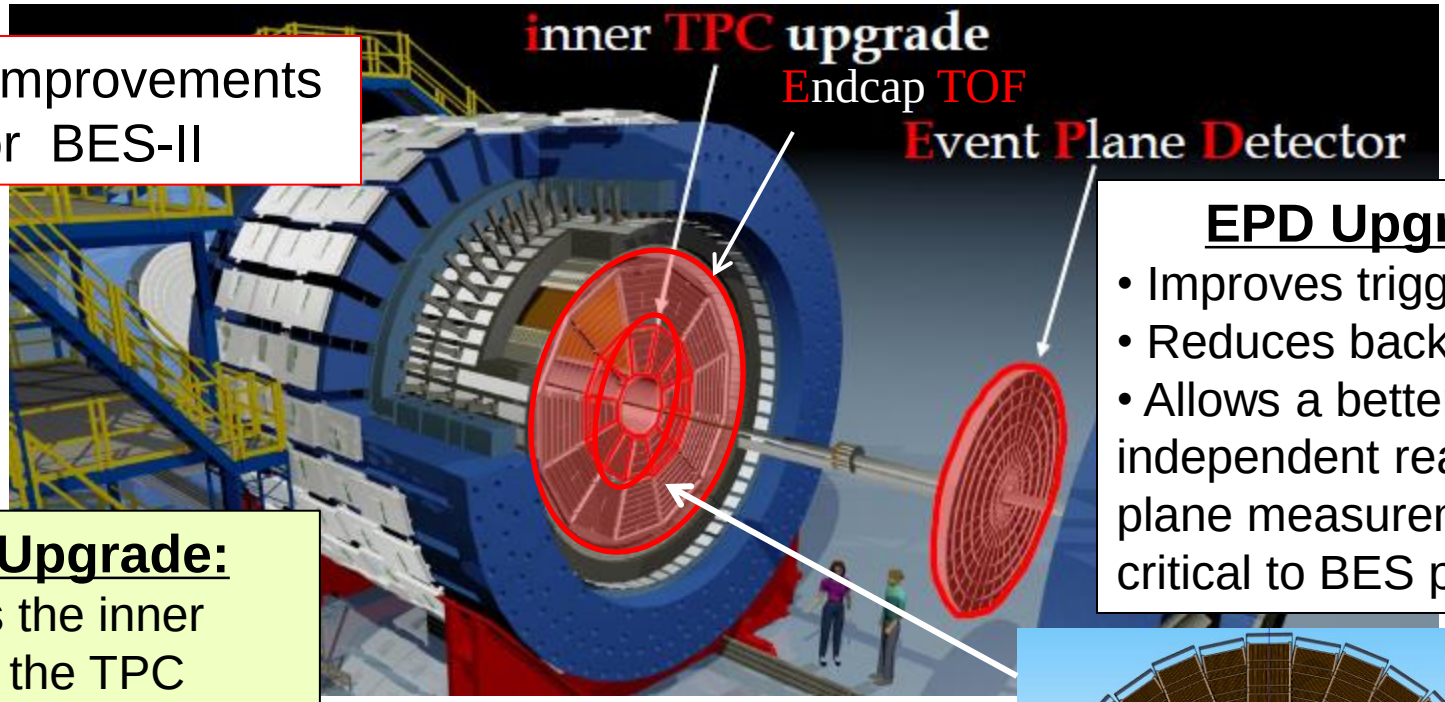
The STAR Upgrades and BES Phase II

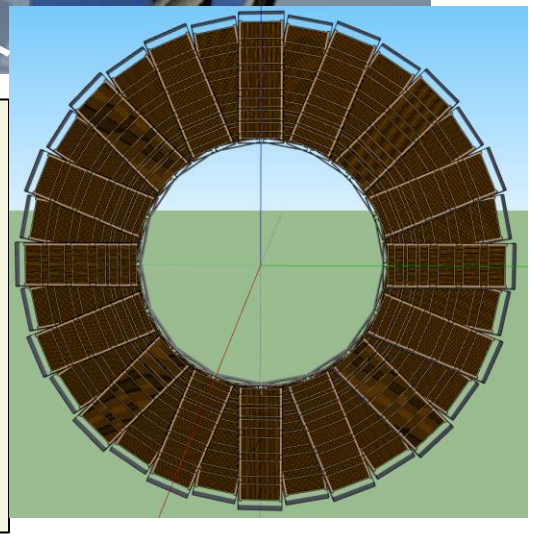
Major improvements for BES-II



EPD Upgrade:
- Improves trigger
- Reduces background
- Allows a better and independent reaction plane measurement critical to BES physics

iTPC Upgrade:
- Rebuilds the inner sectors of the TPC
- Continuous Coverage
- Improves dE/dx
- Extends η coverage from 1.0 to 1.5
- Lowers p_T cut-in from 125 MeV/c to 60 MeV/c

EndCap TOF Upgrade:
- Rapidity coverage is critical
- PID at η = 0.9 to 1.5
- Improves the fixed target program
- Provided by CBM-FAIR



Summary of the plan

	Near term (Runs 11-13)	Mid-decade (Runs 14-16)	Long term (Runs 17–)
Colliding systems	*p*+*p*, A+A	*p*+*p*, A+A	*p*+*p*, *p*+A, A+A, *e*+*p*, *e*+A
Upgrades	FGT, FHC, RP, DAQ10K, Trigger	HFT, MTD, Trigger	Forward Instrum, eSTAR, Trigger
(1) Properties of sQGP	Υ, $J/\psi \rightarrow ee$, m_{ee}, v_2	Υ, $J/\psi \rightarrow \mu\mu$, Charm v_2, R_{CP}, corr, Λ_c/D ratio, μ-atoms	*p*+A comparison
(2) Mechanism of energy loss	Jets, γ-jet, NPE	Charm, Bottom	Jets in CNM, SIDIS, *c*/*b* in CNM
(3) QCD critical point	Fluctuations, correlations, particle ratios	Focused study of critical point region	
(4) Novel symmetries	Azimuthal corr, spectral function	*e*-μ corr, μ-μ corr	
(5) Exotic particles	Heavy anti-matter, glueballs		
(6) Proton spin structure	W A_L, jet and di-jet A_{LL}, intra-jet corr, $(\Lambda+\bar{\Lambda})$ D_{LL}/D_{TT}		$\bar{\Lambda}$ D_{LL}/D_{TT}, polarized DIS & SIDIS
(7) QCD beyond collinear fact	Forward A_N		Drell-Yan, F-F corr, polarized SIDIS
(8) Properties of initial state			Charm corr, Drell-Yan, J/ψ, F-F corr, Λ, DIS, SIDIS

Measurements listed when they first become possible

Many will continue in future periods

Plan presented in 2011

Summary of the plan

	Near term (Runs 11-13)	Mid-decade (Runs 14-16)	Long term (Runs 17–)
Colliding systems	*p+p*, A+A	*p+p*, A+A	*p+p*, *p+A*, A+A, *e+p*, *e+A*
Upgrades	FGT, FHC, RP, DAQ10K, Trigger	HFT, MTD, Trigger	Forward Instrum, eSTAR, Trigger
(1) Properties of sQGP	Υ, $J/\psi \rightarrow ee$, m_{ee}, v_2	Υ, $J/\psi \rightarrow \mu\mu$, Charm v_2, R_{CP}, corr, Λ_c/D ratio, μ-atoms	*p+A* comparison
(2) Mechanism of energy loss	Jets, γ-jet, NPE	Charm, Bottom	Jets in CNM, SIDIS, *c*/*b* in CNM
(3) QCD critical point	Fluctuations, correlations, particle ratios	Focused study of critical point region	
(4) Novel symmetries	Azimuthal corr, spectral function	*e*-μ corr, μ-μ corr	
(5) Exotic particles	Heavy anti-matter, glueballs		
(6) Proton spin structure	W A_L, jet and di-jet A_{LL}, intra-jet corr, $(\Lambda+\bar{\Lambda})$ D_{LL}/D_{TT}		$\bar{\Lambda}$ D_{LL}/D_{TT}, polarized DIS & SIDIS
(7) QCD beyond collinear fact	Forward A_N		Drell-Yan, F-F corr, polarized SIDIS
(8) Properties of initial state			Charm corr, Drell-Yan, J/ψ, F-F corr, Λ, DIS, SIDIS

BES-I **BES-II**

Measurements listed when they first become possible

Many will continue in future periods

RHIC has been adaptable to science needs

2010-13 **2014-16**

BES-I **BES-II**

RHIC has been adaptable to science needs

2010-2013	2014	2015	2016	2017	2018	2019	2020		2022+
Au+Au p+p	Au+Au	p+p p+A	Au+Au d+Au	p+p Au+Au	Isobar Au+Au	Au+Au	Au+Au		Au+Au pp,pA
ΔG, QGP property	Charm flow	Ref. A_N	D_c, Λ_c Υ, Jets	Fc sign	CME, $\Lambda\uparrow$	Critical Point, Phase Transition			Jets, Υ forwardA_N
BES-I	200, 14.5	200	200-19.6	500, 62.4	200, 27	BES-II 11-20	BES-II 7-11		200

BES-I **BES-II**

Expand to include several programs:
p+A in run 15,
pp500 in run17,
Isobar (Zr, Ru-96) in run 18
BES-II more compelling, detector and machine upgrades in 2018
Future high-luminosity jets and Upsilon in 2020+
3+1D hydrodynamics and Unique Cold QCD (DY) portal to EIC

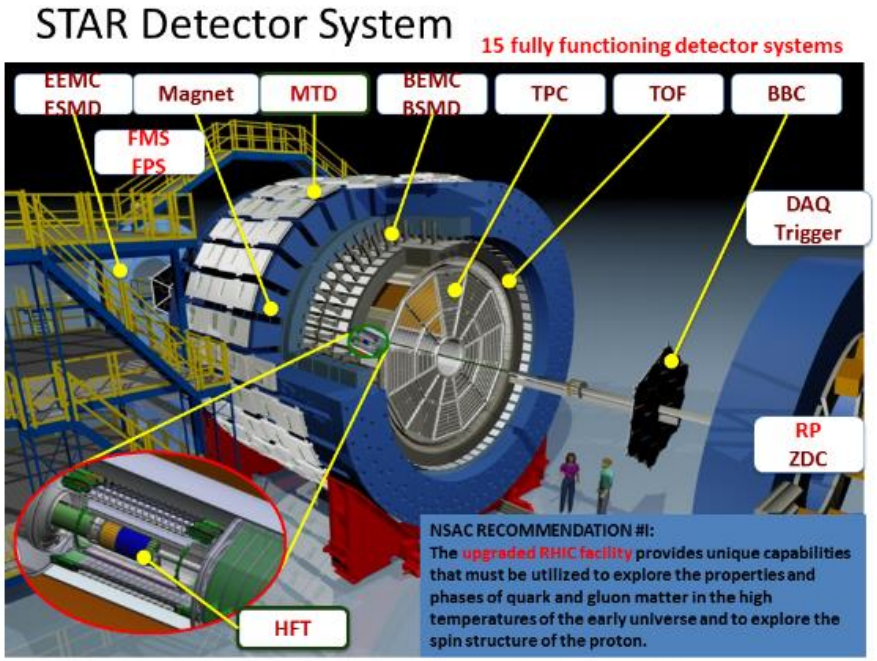
STAR is a multi-purpose detector; with modern capabilities

Period	Physics	Upgrades
2008	Generic	Trigger QT
2009	Generic	TPC/DAQ1000
2010-2011	BES I, PID	TOF
2013--2015	Heavy-Flavor	HFT, MTD
2015--2016	Heavy-Flavor Diffractive, nPDF	FMS, FPS, Roman Pots
2017	Spin Sign Change Diffractive	FMS Post-shower
2018	Isobar (Zr, Ru), CME, dileptons	(EPD?)
2019--2020	BES II	iTPC, EPD, CBM endcap TOF
2022-2023	High-statistics Unbiased Jets, Open Beauty, PID FF Drell-Yan, Longitudinal correl	Forward Upgrade, HFT+?

>50M$ worth of upgrades going into 2019+

- reports
- Simulations
  - 2007 R&D
  - 2008 (FY09) R&D
  - Capital Equipment Requests for FY09
  - STAR RD and upgrades for 2014
  - STAR RD and upgrades for 2014
- eSTAR LoI Draft
- eSTAR Task Force

"The Future" documents

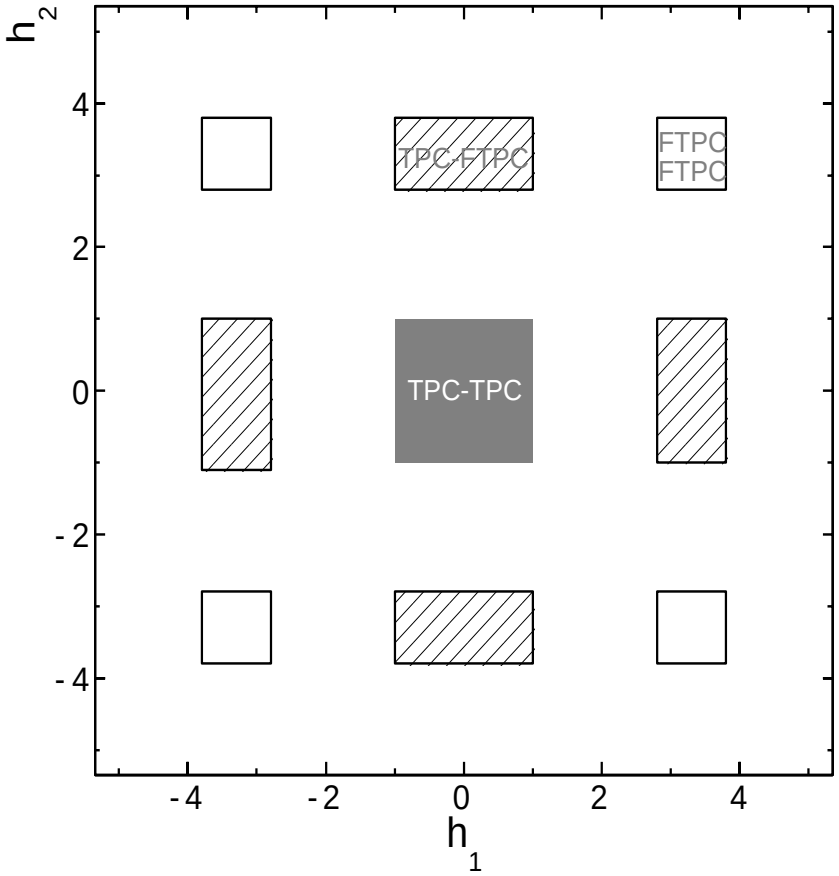


X10³ increases in DAQ rate since 2000, most precise Silicon Detector (HFT)

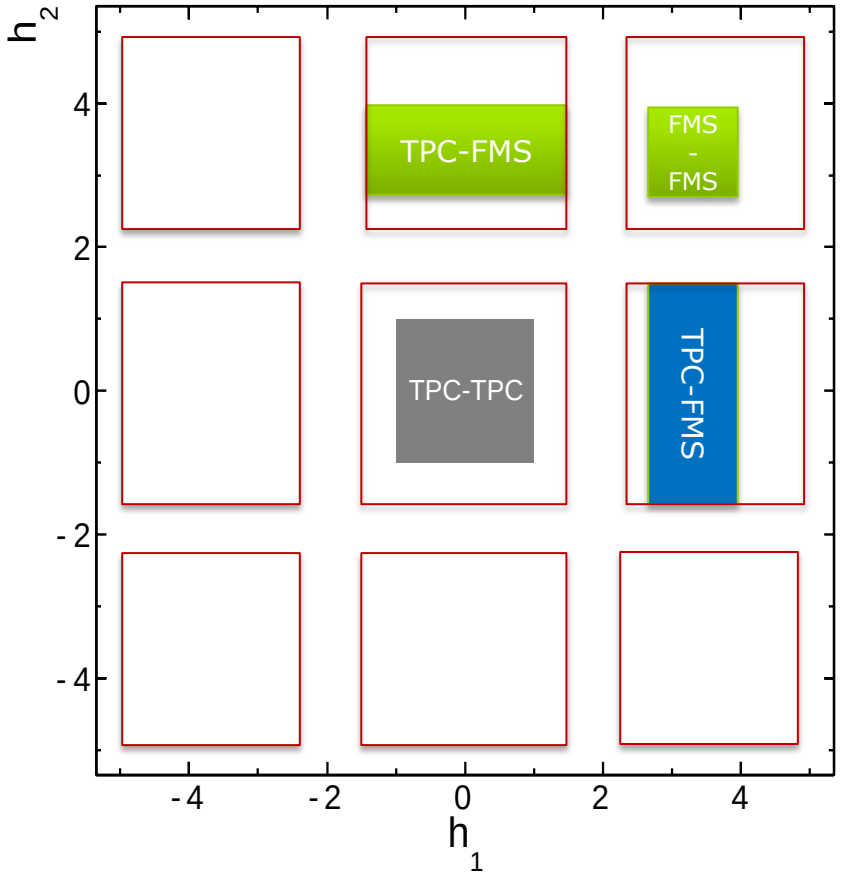
1. Post-shower **proposal** and **review report** May 2016
2. The RHIC Cold QCD Plan from 2017 to 2023: A portal to the EIC - Jan. 2016
   draft: **December 2015**
3. Endcap TOF proposal-Jan. 2016
   draft: **Jan. 14, 2016**
4. Event-Plane **Proposal-May. 2016**
5. SN0648 - January, 2016, **STAR Forward Calorimeter and Forward Tracking Systems beyond BES-II (a case study)**
6. SN0644 - Nov. 29, 2016, **Technical Design Report for the iTPC Upgrade**
7. SN0640-Oct. 19, 2015, **Physics Opportunities with STAR in 2020+**
8. SN0639-Oct. 15, 2015, **Letter of Interest: CBM TOF as STAR Endcap TOF for BES-II at RHIC**
9. SN0625-May. 19, 2015, **RHIC Beam Use Request for runs 16 and 17**
10. SN0619-Feb. 18, 2015, **A Proposal for STAR Inner TPC Sector Upgrade (iTPC)**
11. SN0617-Jan. 19, 2015, **a case for run16 pp510 (supplementary material)**
12. e-Print: **arXiv:1502.02730**,
    The Hot QCD White Paper: Exploring the Phases of QCD at RHIC and the LHC
13. e-Print: **arXiv:1501.06477**,
    Exploring the properties of the phases of QCD matter - research opportunities and priorities for the next decade
14. SN0606-Jun. 2, 2014, **STAR Beam Use Request (BUR) for run-15 and run-16**
15. SN0605-Jun. 1, 2014, **A polarized p+p and p+A program for the next years**
16. SN0598-Mar. 28, 2014, **Studying the Phase Diagram of QCD Matter at RHIC**
17. SN0592-Oct. 1, 2013, **eSTARLetter of Intent**
18. 2014 Computing plan https://drupal.star.bnl.gov/STAR/starnotes/private/psn0622
19. SN0588-Aug. 21, 2013, **EsNETHEP/NP Science Network Requirements 2013**
20. STAR Decadal Plan, December 2010, **https://drupal.star.bnl.gov/STAR/starnotes/public/sn0645**

Rapidity Coverage (BES-II)

TPC+fTPC (2001-2012)



TPC+iTPC+eTOF+EPD+FMS (2019--)



Physics Opportunities beyond BES-II

Physics Goal	Measurements		Requirements						
			Base	fCal	fTS	RP	HFT+	BSMD	Streaming
Nuclear PDFs	DY, Direct photons +J/Psi R_{pA}	★■	✓	✓	Enh				
Nuclear FF	Hadron + Jet	★■	✓						Enh
Polarized Nuclear FF	Hadron + Jet	★	✓						
Odderon & Polarized Diffraction	A_{UT} of pion + forward proton	★		✓		✓			
Low-x ΔG	Di-jets	★	Enh	✓	✓				
High-x Transversity	Hadron+jet	★■		✓	✓				
Mapping the Initial State in 3-D: QGP Transport Properties	R. Plane Rapidity de-correlations	★	Needs iTPC						
	Ridge $\|\Delta\eta\|<3$	★	Needs iTPC						
	Ridge $\|\Delta\eta\|<6$	★	Needs iTPC		✓				
	Forward Energy Flow	★	Needs iTPC	✓					
Effects of Chiral Symmetry at $\mu_B=0$	Di-lepton spectra at $\mu_B=0$	★■	Needs iTPC				HFT out		Enh
	Extended LPV observables	★■	Needs iTPC						Enh
Internal Structure of the QGP and Color Response	Υ(1S,2S,3S)	○	✓						
	B R_{AA}	★■	✓				✓		
	B v_2	★■	✓				✓	✓	✓
	B-tagged Jets	○	✓				✓		
	Jets	○	✓						Enh
	γ –Jets	○	✓					✓	
Phase Diagram and Freeze-out	BES-II Observables at $\mu_B=0$	★	Needs iTPC						
	C6/C2, C4/C2	★	Needs iTPC						
The Strong Force	Exotics and Bound States (di-Baryons)	★	Needs iTPC						✓

1. Define QCD Phase Structure
2. Study Chiral Properties
3. Map T dependence of η/s
4. Test K_T factorization and Universality

Extended coverage and targeted upgrades open up many opportunities for a diverse scientific program in 2020+

✓ Measurement needs upgrade Enh : Enhances measurement, but is not required

★ Unique to STAR ○ Complementary to sPHENIX ■ Complemented by LHC and/or JLab

Green highlighted rows require only continued running with STAR as instrumented for the BES-II

Base : STAR as instrumented for the BES-II
iTPC : Inner sector TPC upgrade extending coverage from $|\eta|<1$ to $|\eta|<1.5$
fTS : Forward Tracking System
fCal : Forward Electromagnetic and Hadronic Calorimeters
HFT+ : An extended faster heavy flavor tracker
Streaming : An electronics and DAQ upgrade allowing significant increase in minbias data rate
BSMD : Replacing the BSMD readout
HFT out: Di-lepton spectra at $\mu_B=0$ improved by running with less material

Summary

- Successful run16
- Compelling Heavy-Ion Programs for run 16 and run 18
  - Completion of Heavy-Flavor program for HFT+MTD
  - Decisive test of Chiral Magnetic Effect
  - Quantifying the role of external field in Global Hyperon Polarization
- Compelling Spin Program in run17
  Three measurements related to TMD evolution and sign change
  (A_N $W^{+/-}$, γ, DY)
- Maintain track record in Results and Publications
- Preparation for BES II and beyond
  (High-statistics of rare probes, 3+1D hydro and Cold QCD)

Work in progress and concerns:

- Longer term plan beyond 2020
- Operation and resources to maintain a viable program
- Maintain an active scientific collaboration
- Computing and Analysis Resources